[redacted]

CONTRACT REQUIREMENTS	CONTRACT ITEM	MODEL	CONTRACT NO.	DATE
Exhibit E- Para. 3.8		LEM	NAS 9-1100	20 Dec 62

Type I

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REPORT

NO. LPL-550-1 DATE: May 31, 1963

RELIABILITY PLAN [U]

G-4

CODE 26512

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REVISIONS

DATE	REV. BY	REVISIONS & ADDED PAGES	REMARKS

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CONTENTS

APPENDICIES

Code 26512 Eng-23A

REFERENCES

(a) NASA- Exhibit A- Statement of Work-Lunar Excursion Module, Project Apollo, dated December 20, 1962- Contract No. NAS 9-1100

(b) NASA- Exhibit B- Technical Approach Lunar Excursion Module, December 20, 1962- Contract No. NAS 9-1100

(c) NASA- Exhibit C- Hardware Delivery List Lunar Excursion Module- December 20, 1962- Contract No. NAS 9-1100

(d) NASA- Exhibit D- GFP/GFE List Lunar Excursion Module, December 20, 1962- Contract No. NAS 9-1100

(e) NASA Exhibit E- Documentation Requirements Lunar Excursion Module December 20, 1962- Contract No. NAS 9-1100

(f) MIL-R-27542 (USAF)- Military Specification- Reliability Program Requirements for Aerospace Systems, Subsystems, and Equipment, dated 28 June 1961.

(g) Quality Program Provisions for Space System- Contractors, NASA Quality Publication NPC 200-2, April 1962 Edition.

(h) Grumman Report LPL-600-1, 5/15/63- The Test Plan for the Lunar Excursion Module

(i) Grumman Report LED 520-1, 5/15/63- Design Criteria and Environments- LEM

SECTION 1

1.1 Introduction

The Grumman LEM Reliability Plan established by this document, contains the Grumman methods and procedures to comply with the Reliability requirements of NASA Contract 9-1100, MIL-R-27542 (USAF), and NASA Quality Publication NPC 200-2, dated April 1962. This document, upon concurrence by NASA, shall constitute the basis for the LEM Reliability Program and the methods by which the reliability objectives will be measured.

This document will be revised either as necessary to incorporate pertinent changes,at intervals not to exceed 6 months, or at the written request of NASA. Revisions to this document to incorporate changes due to revisions of NASA Reliability Specification shall be processed in a manner consistant with standard Grumman contract change procedure.

1.2 Relation to Quality Control Requirements-

The LEM Quality Control Program Plan, submitted separately describes the LEM Quality Control procedures and methods. This document shall supplement the requirements of the Quality Control Program Plan in the attainment of common Reliability and Quality Control goals. Typical Reliability and Quality Control interfaces occur in the activities of design review, vendor control,and data acquisitions and analyses.

1.3 Basic Requirements

1.3.1 This Reliability Plan is submitted in accordance with the requirements of Appendix II paragraph 3.8 of reference (e). Grumman shall submit the required document initially four months after go-ahead and shall update as necessary or at the written request of MSC-ASPO and at six month intervals after acceptance.

1.3.2 This Reliability Plan is prepared in accordance with the requirements of paragraph 2.4 of reference (a) and paragraph 3.8 of reference (e). These paragraphs are as follows:

"2.4 Reliability and Quality Assurance- As an integral part of the design, development, manufacturing and test program, the Contractor shall plan and implement a reliability and quality assurance program to assure that a high level of quality is achieved in the manufacturing and test process and that considerations of mission reliability and crew safety are exhaustively treated and controlled during the design, development and test program. The Reliability Program will be developed along the lines set forth in MIL-R-27542 (USAF) and NASA Quality Publication NPC-200-2 entitled Quality Assurance Provisions for Space System Contractors."

"3.8 Reliability Plan- The contractor shall prepare a Reliability Plan that describes in detail the Contractors' reliability program including subcontractors reliability program requirements in accordance with MIL-R-27542."

1.4 Policy and Scope of Reliability Program-

1.4.1 Policy- It is Grumman policy to produce in the most economical manner a product which satisfies or exceeds the customer's reliability requirements. Reliability is considered an inherent product characteristic, it is not a commodity separate from the product. Reliability is therefore designed and manufactured into the product. Reliability control, to be effective,is integrated into the basic development of the product.

In order to provide assurance that the stringent reliability requirements have been met, a program of reliability control engineering has been formulated to run concurrently with, and to compliment the LEM design and development. Section 3 of this plan describes the details of this program. In conjunction with Grumman's reliability program, a similar reliability program will be imposed on all vendors that supply sub-systems and equipment for the LEM. The vendor requirements are incorporated in the Equipment Design Specifications and the Vendor Requirement Documents. Illustrative example of such requirements are contained in Appendix A of this plan.

1.4.2 Scope- The Grumman Reliability Programs activities shall include the following:

(a) Review of reliability requirements
(b) Review of environmental requirements
(c) Apportionment of system Requirements
(d) Design analysis and Control of the design phase
(e) Design reviews'
(f) Parts Application and Standardization
(g) Reliability Estimates
(h) Reliability Surveillance of the test program
(i) Subcontractor Direction and monitoring
(j) Reliability review of the fabrication phase
(k) Reliability training
(l) Failure Reporting and feedback system
(m) Failure mode and effects analysis

SECTION 2

2.1 Reliability Management and Controls-

The position of the LEM Reliability organization with relation to the LEM organization is shown in figure 2-1. This organization has been arranged to assure working compatibility and positive response to direction from the Manned Spacecraft Center organization. Reliability activities are shown in two positions on the organization chart.

2.1.1 Reliability Director

The Reliability Director, in a staff position to management reports directly to the LEM Program Director. He is in a position to examine critically any facet of the LEM program.for assuring high confidence of mission success and crew safety and to act as consultant to the Engineering Manager, Quality Control Manager, Test and Support Manager, and Manufacturing Manager.

The function of the Reliability Director through this surveillance position will be to assure the Program Director that a Reliability Program is instituted.

2.1.2 Systems Reliability Engineer

The Systems Reliability Engineer, associated with the System Engineering section which reports directly to the Engineering Manager and Project Engineer, is responsible for delineating and implementing the reliability program to assure that the delivered LEM meets or exceeds the minimum reliability requirements specified by NASA. The reliability control program is designed so that all phases of the design, development, production, and use of the system, sub-systems, and equipments, Grumman made or subcontracted, are controlled.

The Reliability Engineers that are associated with the LEM Systems Reliability Engineering group have been assigned on a permanent basis in accordance with manpower allocations from the Grumman Reliability Control Section of Engineering. Direction of these personnel for LEM Reliability activities is given by the LEM Systems Reliability Engineer. Technical reliability techniques, philosophy, and administrative procedures are given by the Reliability Control Section of Engineering.

2.1.2.1 The responsibilities of the LEM Systems Reliability Engineering are:

To establish the system, subsystem, and equipment reliability requirements and prepare continuous reliability estimates based on the analysis of these equipments. The specific tasks performed are:

a- Reliability Program Plan preparation to NASA-MSC for approval.
b- Reliability input to Vendors Requirement Document and Specification
c- Vendor Reliability Program review
d- Initial Selection of Vendors - Reliability review and requirements
e- Negotiation of Reliability Control Program with Vendors.
f- Apportionment of System & Subsystem Reliability Requirements for mission success and crew safety.
g- Estimating of System & Subsystem Reliability
h- Liaison with Apollo contractors

2.1.2.1 (continued)

i- Coordination with Quality Control in establishing process standards.
j- Monitoring of vendor for reliability program compliance.
k- Approval of drawings & procurement specifications for reliability adequacy
l- Define the mathematical model required to predict, apportion, and assess reliability and crew safety.
m- Support training program

2.1.2.2 To conduct system and subsystem optimization studies in order to justify the selection of the design based on all requirements. The tasks include:

a. Configuration Analyses
b. Circuit Analyses
c. Failure Effect Analyses
d. Maintainability Analyses
e. Environmental Analyses
f. Participation in Design Reviews
g. Evaluation of checkout procedures and their implications on mission success and safety.

2.1.2.3 To select components and parts that will survive the environments experienced during the LEM mission and establish acceptable parts lists. Tasks are:

a. Component Part review
b. Component Part Specification review and approval
c. Component Part Test plans

2.1.2.4 To establish a reliability assurance program which encompasses all development, qualification, acceptance, ground, and flight test program so that continuous documentary evidence is accrued for comparison with the reliability goals. The tasks include:

a. Review of all test plans
b. Approval of all test plans
c. Planning and direction of special reliability tests
d. Monitoring of Grumman and vendor tests for reliability data.

2.1.2.5 To establish a Data Control Program so that continuous data may be supplied to the Grumman team and NASA- MSC. The tasks include establishing the following IBM programs:

a. Reliability Estimating program- a mathematical model of the entire LEM system is programmed so that reliability estimates may be obtained quickly and continuously. Required by NASA.

b. Component and Part Data- a tabulation of all components and parts used on all subsystem and equipments in the LEM.

c. Test and Test Summary Data- a listing of all tests to include data on reason for test, test environments, information to be obtained from the test, reliability data anticipated, test data to be recorded, etc.

d. Failure data- a listing of failure reports from Grumman and Vendor tests. This listing will include selected development tests, qualification, acceptance, ground, and flight test.

2.2 Procedure for Reporting Reliability Activities to Management.- Three paths exist in which the activities of the Systems Reliability Engineering function are reported to Grumman Management. Each path is of equal importance in transmitting significant reliability information. Figure 2-2 illustrates these paths.

The first path shown is as follows:

Systems Reliability Engineering Function reports through the Systems Project Engineer to the Engineering Manager who reports directly to the Program Manager.

The second path shown is as follows:

System Reliability Engineering Function reports directly to the Program Manager at the regularly scheduled weekly Management meetings.

The third path shown is as follows:

The Reliability Director, may request at any time a Reliability Status Report of any specific problem area. These reports are then submitted by the Reliability' Director to the Program Director and the Program Manager.

2.3 Grumman LEM Data Center- The LEM Data Center will be a central project function. All system and subsystem engineering activities will be coordinated by the Systems Coordination Group of the Systems Analysis and Integration Section. The Reliability Engineering activity input to this group will be in the form of four programs. These programs are:

a. Reliability mathematical model for reliability apportionment, estimating, and mission simulation.

b. Acceptable parts listing to include qualified parts, limited life parts, and standard parts.

c. Test indentification and results listing

d. Failure reporting and correction program.

The Reliability Engineering activity will be able to obtain from the data center the following types of data:

a. Thermal analyses
b. Stress reports
c. Environmental analyses

2.4 Reliability Indoctrination and Training- Reliability Indoctrination and training of all LEM personnel will be planned and implemented by the LEM Systems Reliability Engineering activity in conjunction with the Grumman Reliability Control Section of Engineering. (See figure 2-3)

2.4.1 The Grumman Reliability Control section has as one of its major responsibilities, the reliability and maintainability education and training of all Grumman personnel. For the Grumman personnel assigned to LEM, a program is being established to provide this education and training for engineering, manufacturing, quality control and flight test. All personnel will be instructed in:

(a) the importance of reliability in the LEM program
(b) the contribution of each person to the achievement of the LEM reliability goals.
(c) the latest tools and techniques available for designing and building reliability into the LEM

2.4.1 (continued)

(d) the functions of the Reliability group as an engineering service organization
(e) the techniques for measuring achieved reliability.

In order to achieve these objectives, the following techniques are utilized:

(1) A series of lectures which stress the basic definitions, philisophy, techniques, and tools of reliability and maintainability. This series is repeated as required.

(2) A series of lectures in each of the major departments to stress the particular contribution of that department to LEM reliability and maintainability and the reliability and maintainability tools of special value to that department.

(3) Reliability memoranda are distributed to specific areas in Grumman as new techniques and tools are developed and/ or discovered by Reliability Control personnel. Members of the various departments are encouraged to forward to Reliability Control any reliability or maintainability information which they find so that it may be disseminated to the areas where it can be of value.

(4) Manuals containing reliability and maintainability information are made available to members of the various engineering organizations.

(5) Reliability and maintainability training films are utilized, as they become available, in those areas where they are deemed valuable.

(6) In the engineering department, members of the Reliability Control section are assigned to the various systems and subsystem groups to act as consultants in the areas of reliability and maintainability. Should the need arise, similar arrangements are made with the other departments.

2.4.1 (continued)

A reliability and maintainability training program is also conducted within the Reliability Control section for the purpose of (1) introducing new members of the Reliability Control section to the Grumman Reliability Control system, (2) presenting the latest techniques and tools for reliability and maintainability analysis, production, testing, apportionment, etc., and (3) presenting the benefits derived by section members attending professional courses and symposia. Periodic lectures, round-table discussions, films, and memoranda are the primary means of disseminating this information. Maximum use is also made of such documents as the NASA "Reliability Abstracts and Technical Reviews". Bibliographies such as those prepared by Tibor Vincze (ASTIA Document 255988)and J. H. Motes ("Proceedings of the Ninth National Symposium on Reliability and Quality Control", pp. 556-581, Jan. 1962) are also utilized wherever possible.

2.5 Subcontractor control- The subcontractor reliability requirements are being incorporated in the Equipment Design Specifications and Vendor Requirement Documents. The following sections of these documents reflect the requirements and tasks. Appendix A of this report contains an example of these requirements.

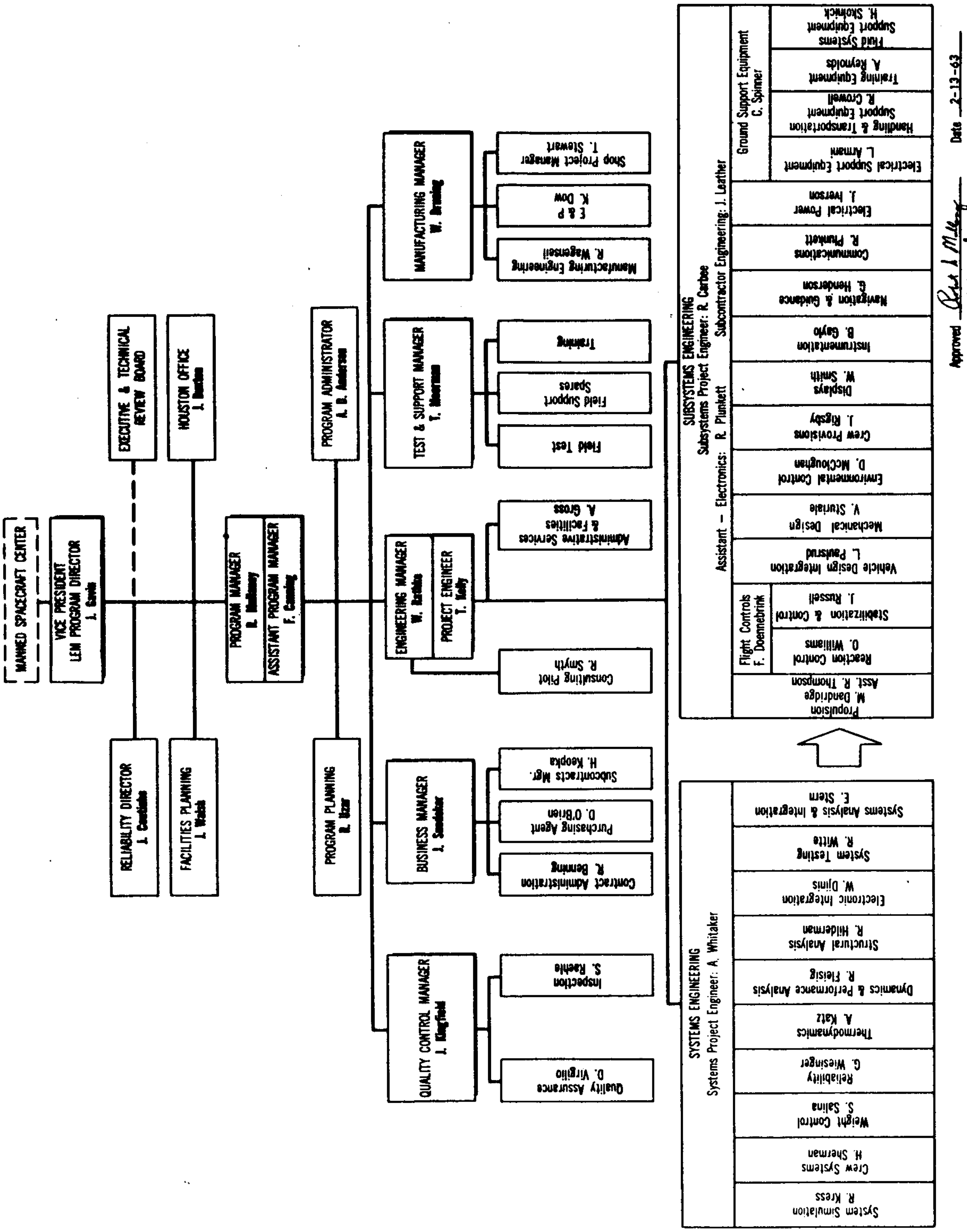
2.5.1 Reliability Requirements- Reliablity requirements are specified in the Equipment Design Specification (LSP-) in the following paragraphs:

(a) Paragraph 3. -Reliability Goal
(b) Paragraph 4.4. - Reliability Assurance
(c) Table II Environmental and LoadConditions
(d) Table IV Typical Life Cycle

2.5.2 Reliability Tasks- Reliability tasks are specified in the Vendor Requirement Document (LVR- -)in Section C paragraph 6.(LVR- -) in Section D paragraph 3.

2.5.4 Reliability Documentation- Reliability documentation is specified in the Vendor Requirement Document (LVR- -) in Section E paragraph 7

2.5.5 Reliability- Instructions for Proposal- Instructions for the proposal for reliability are specified in Section G paragraph 6.



LEM Program Organization Chart

FIGURE 2-1

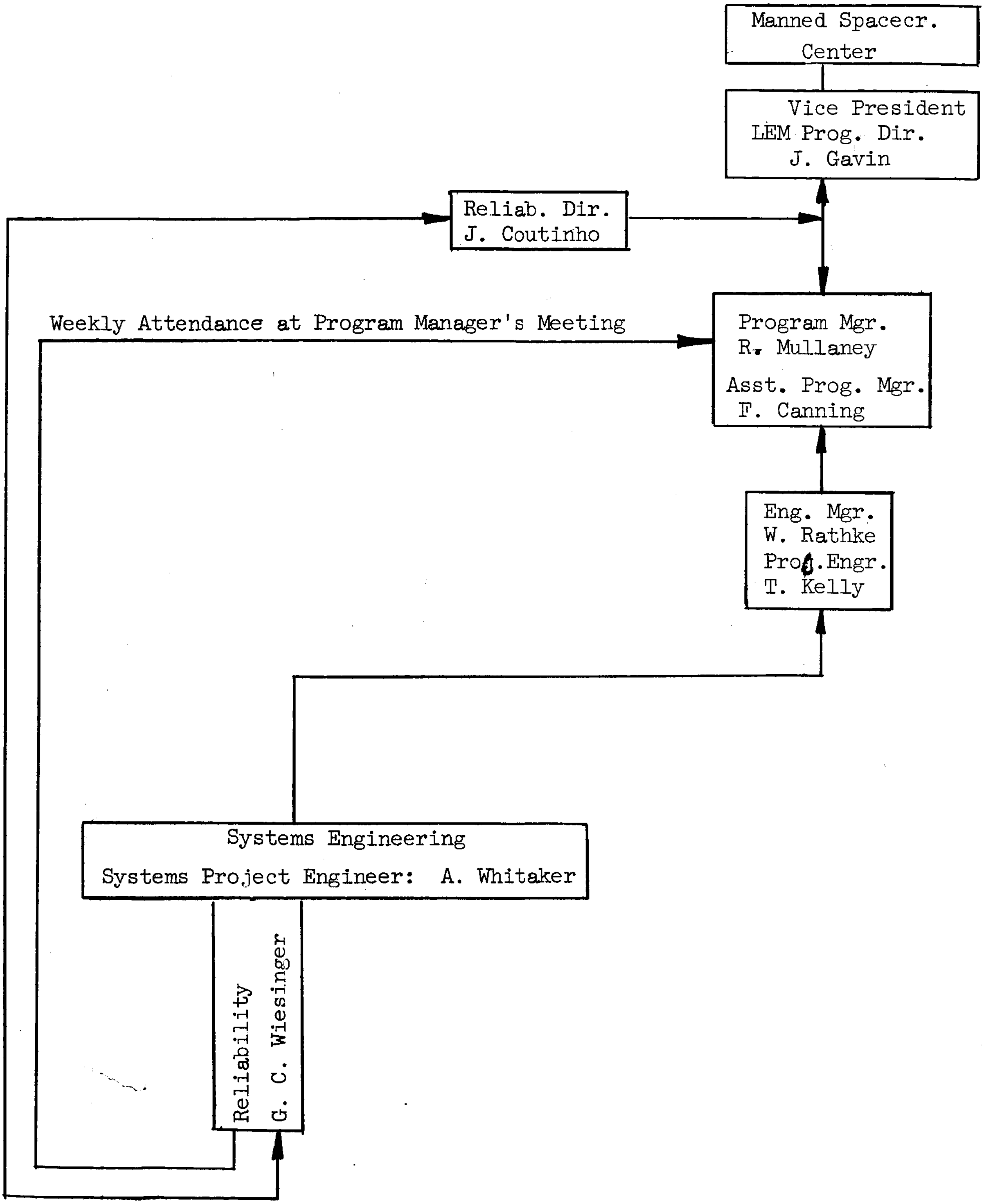


FIGURE 2-2

REPORTING OF RELIABILITY ACTIVITIES

TO MANAGEMENT

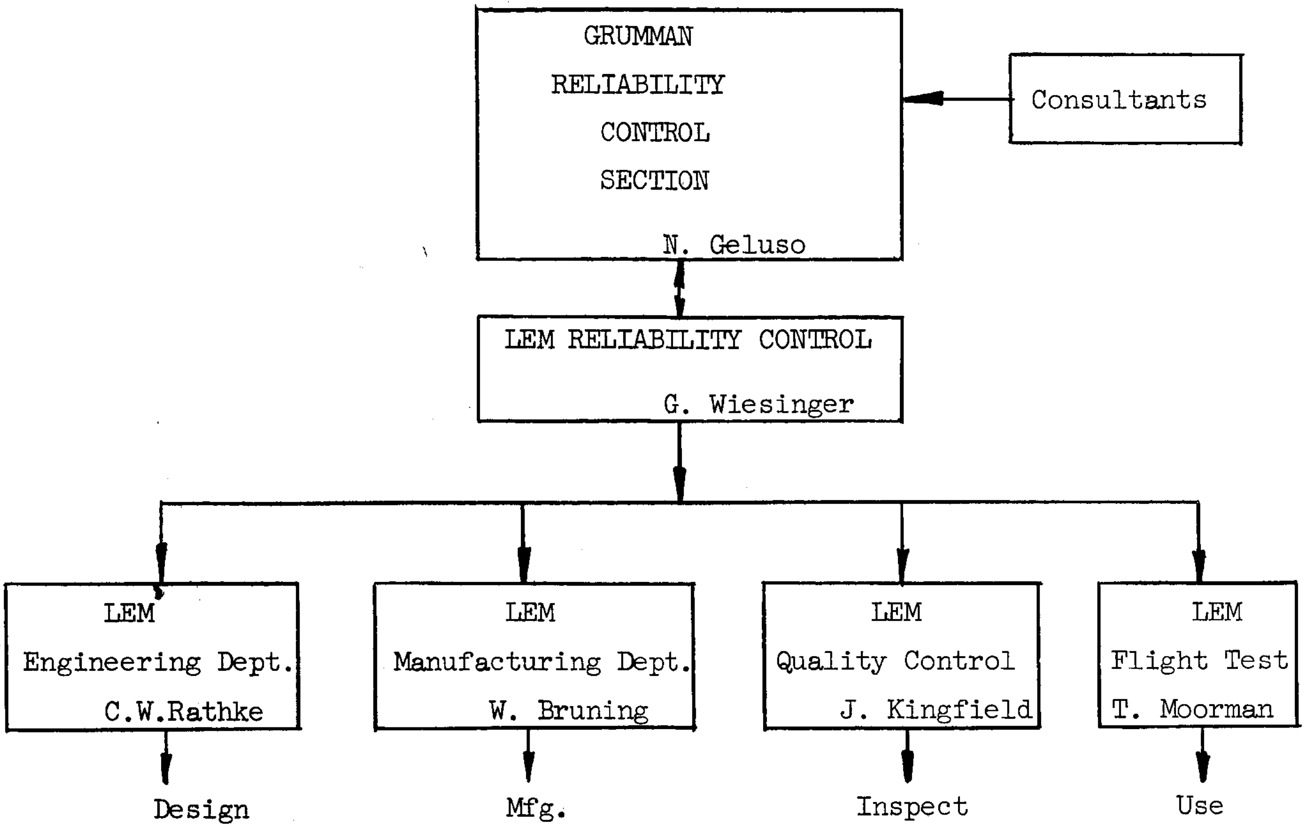


FIGURE 2-3

RELIABILITY TRAINING FLOW CHART

SECTION 3

RELIABILITY ANALYSIS AND VERIFICATION

3.1 This section describes the planned analytical effort and approach to verify the reliability goals for the LEM. The program described herein applies to the Grumman direct effort, the vendor effort, and in conjunction with NASA-MSC support, and data furnished by the GFE contractors, Figure 3-1 indicates the phasing of the reliability activities, to the GFE items.

3.2 Reliability Goals and Apportionment.

3.2.1 Reliability Goals - The LEM numerical reliability goals are specified in reference (b) in the following paragraphs:

(a) Paragraph 2.1.3.1

"<u>Mission Reliability</u> - The probability of accomplishing the mission objectives shall be 0.90 of this overall reliability goal, the reliability goal apportioned to the Lunar Excursion Module shall be 0.984".

(b) Paragraph 2.1.3.2.2

<u>Emergency</u> (Crew Safety) - The probability that none of the crewmen shall have been subjected to conditions greater than the emergency limits specified in the crew requirements section shall be 0.999. Of the overall crew safety goal, the crew safety goal apportioned to the Lunar Excursion Module shall be 0.9995".

3.2.2 Reliability Apportionment - The overall LEM reliability goals of paragraph 3.2.1 are to be apportioned to the subsystems and equipments contained in the LEM and to those ground support equipment that directly support this equipment at time of launch.

3.2.2.1 <u>Present Apportionment Approach</u> - Crew Safety & Mission Success profiles, in the form of reliability block diagrams for each major mission phase, are determined. Equipments required for the total mission and each mission phase are listed. The LEM Mission Profile provides the detailed phase time parameters. The equipment operational times, environments and possible redundancies of each equipment are estimated. In a parallel effort, an original estimate of the relative failure rate, K_{ci}, of equipments under standard operating and environmental conditions is obtained for the

3.2.2.1 (Continued)

primary LEM equipments. This K_{ci} is classified as the complexity of the its equipment. It is determined that the estimated complexities are proportional to the apportioned failure rates: the factor of proportionality being such that the apportioned failure rate of the equipment can be written βK_{ci}. For non-standard conditions of environment and usage, the corresponding failure rate of equipment is considered to be

$$\beta \cdot K_{ci} \cdot K_{ei} K_{vi}$$

Where K_{ei} is an environmental factor
K_{vi} is a usage factor.

Now equipment i is taken through the mission and the probability of its failure is determined as a function of β. Where mission success requires that no failure of any equipment occurs, the probability of failure of equipment i is calculated to be:

$$\Phi_i = \beta \sum_{M} K_{ci} K_{ei} K_{vi} t_m$$

Where t_m was the time of the ith equipment in the m^{th} phase of the mission and β is a constant. The probability that none of the equipments failed during the mission is now equated to R (=0.984), the probability of mission success.

Thus: $$R_T = 1 - B \sum_i A_i$$

And: $$B = \frac{1 - R_T}{\sum A_i}, \quad \Phi_i = \left(\frac{1 - R_T}{\sum_i A_i} \right) A_i$$

[illegible]:

[illegible], [illegible] apportioned reliability of equipment for the entire mission is obtained, i.e.:

$$R_i = 1 - \Phi_i$$

3.2.2.2 Failure rates used throughout this program will be derived from MIL-HDBK-217 and various GAEC and Vendor sources. Reliability data presented has been used in comparative configuration studies only and is not presented as a prediction of the ultimate reliability achievable for a particular equipment. Specific data sources will be listed for each part in subsequent reports as configurations are more clearly defined and specific parts have been selected.

3.2.2.3 Future Apportionment Approach - A general electronic data processing (EDP) program, for use with IBM 7094, will be designed and specifications written which will automatize the calculations of system reliabilities from a coded reliability block diagrams. The code will be developed to represent detailed reliability block diagrams with a minimum of mathematical error.

The coding of reliability block diagrams, equipment failure rates, mission times, environmental and usage factors, will be the parameter inputs of the computer. The computer program outputs will be probability of success, R_T for individual mission phases or the entire mission for individual equipments, units or input/output signals.

At various phases of the program the equipment apportionments will be updated and revisions made to the existing Equipment Specifications and Vendor requirement documents. Generally it is anticipated that the future apportionment techniques to be used will reduce the required reliability goal to the vendors due to the consideration of alternate paths of operation and higher equipment utilization. Where the reliability goal must be increased to achieve the degree of success required, Grumman will negotiate with the vendor the new requirements.

3.3 Reliability Control of the Design and Development Phase - This phase of control shall assure that the inherent reliability of the basic design is compatible with the specified requirements of the LEM detail equipment specification. During the design phase the following procedures will be established:

(a) Design engineers will be provided with all existing pertinent information, organized in a suitable manner, to assist them in making decisions which will result in an optimum design. As a minimum, such information will include:

1. The current reliability apportioned requirements and the estimates for those parts and assemblies for which the designer is responsible.

2. All other design requirements such as performance, maintainability, space, weight, interface and interaction requirements, and fail-safe features.

3. All pertinent analyses, such as design configuration, failure effect, circuit, dynamic, heat transfer, applied loads, structural.

3.3 (Continued)

(b) The apportionments, estimates, and analyses of subparagraphs (a) (1) and (a) (3), above will be conducted concurrently with the design, and with the full knowledge and cooperation of the design engineer.

3.3.1 Design Review - Design reviews will be conducted at all major milestones in the program and with reasonalbe frequency throughout the design phases in accordance with the schedule established by the LEM Program Manager and NASA-MSC. Participation in the design reviews shall include qualified personnel from the design, reliability, quality control, parts application, manufacturing and other areas as appropiate of the Grumman LEM organization so that all engineering desiplines having a bearing on the design shall be represented. Reliability participation in the design review shall use the following analyses to evaluate the equipment design.

3.3.1.1 Environmental Effects on Reliability - The contractor will determine the effects of storage, packaging, transportation, handling, maintenance and operational environments on the reliability of the equipment and components. The analysis shall include a determination of the effects of all environments specified in the LEM work statement, both singly and in any possible combination. Where applicable, both operating and non-operating modes will be considered.

3.3.1.2 Applied Loads and Environments - This analysis will consider critical design assumptions and combined environments, including load frequency spectra, mechanical and thermal shock, and vibration, which are necessary to establish the design of structural elements.

3.3.1.3 Configuration Analyses (Trade-off Studies) - Configuration Analyses will be prepared to assist the design engineers in making optimum decisions before a design is frozen. A configuration analysis will compare alternate configurations, logical designs, functional arrangements, or any other schemes affecting the reliability and maintainability of the equipment in such a manner as to assist the designer in selecting the optimum design. A configuration analysis completed after a design decision is made serves no purpose. A systematic effort will be made to consider all possible schemes and arrangements before a decision is made. For each configuration, the significant parameters involved in the particular circumstances will be identified. These parameters usually are cost, performance, life, maintainability, reliability, schedules, fail-safe features, etc.

3.3.1.3 (Continued)

The various configurations under consideration usually consist of different arrangements of components or functions which all yield the same result in the main operating mode, but which may involve different degrees of redundancy and different degraded modes of operation. The significant effect; of each parameter will be evaluated quantitatively by suitable figures of merit. Normally, figures of merit are numbers which are not exact measures of parameters, but rather relative values indicating the importance of a parameter within the scope of a particular investigation for the purpose of establishing the optimum trade-offs and thus arriving at the best configuration.

3.3.1.4 Circuit Analysis - Where applicable, a circuit analysis will be prepared during the design phase to assure optimum application of component parts. The analysis as a minimum will indicate the following data for each part used in each circuit or subassembly of the equipment:

(a) Part Performance rating at the anticipated stresses.

(b) Loadings

(c) Environmental conditions expected during mission.

(d) Derating factors at the environmental stresses.

(e) Expected failure rates at the environmental stress and derating factors.

(f) Mode of failure at the given environmental conditions and derating factors.

(g) Symptoms and consequences of the mode of failure on the circuit and the mission capability of the system.

(h) Compensating provisions inherent in the design or alternate operating modes.

(i) Probability of occurrence of each circuit mode of failure based on the summation of the contributing component part failure rates.

3.3.1.5 Failure Mode and Effects Analysis - An analysis of all conceivable failures and their effects on the mission capability of the system will be conducted during the design phase to uncover critical reliability areas and direct appropriate engineering attention to them. In the early phases of design, the analysis will consider the consequence of failures at the higher levels of assembly. In the later design phases, the analysis shall become progressively more detailed and ultimately will be conducted at the circuit level for electronic equipment and the piece part level (i.e. - valve, gyro, bellcrank, etc.) for non-electronic equipments. The failure effect analysis at the piece part level in electronic equipments will be conducted as a phase of the Circuit Analysis as required in paragraph 3.2.4.2. The results of such an analysis will be reflected in a design which is substantially fault-free in its earliest phase. The results of the analysis will also serve as basic trouble shooting data useful in the design of test and checkout equipment.

A complete failure-effect analysis will be performed on each design and each change to that design.

A review of failures during tests will be conducted monthly, (if failures have occurred), and the effects of these failures on equipment performance will be determined and compared with the effects predicted in the analysis. The failure-effect analysis will be revised if actual failure effects do not confirm the analytical predictions.

The failure-effect analysis will use the format shown as Table III and will include the following:

(a) Block Diagram - Functional block and sequencing diagrams will be used to define the operation of the sub-system and functional groups of circuits or components. The design output requirements for each functional block will be indicated.

(b) Item Number - This is the number assigned to each item in the block for numerical identification.

(c) Assumed Failures - It will be assumed that each functional block will fail in turn. A systematic procedure will be followed, where for each block, each output signal will be assumed to fail in its most critical position or most adverse condition, both singly and in combination with other possible failures resulting in a critical condition. Any condition where the output does not meet the design output requirements will be considered a failure.

3.3.1.5 (Continued)

(c) Assumed Failures - (Con't) - The systematic procedure will assure that all conceivable functional failure modes at the circuit level and higher, considering all anticipated environmental and operating stresses, will be considered.

(d) Possible Cause - This a brief description of the cause of each functional failure in column C, usually the breakdown of a part. Examples are: shorted components, open circuited components, or structural failure. (Identify failed components or parts).

(e) Symptoms and Consequences - Symptoms and consequences of each functional failure on the next higher level of assembly and on the mission capability of the system.

(f) Compensating Provisions - Compensating provisions inherent in the design, or alternate operating modes. This section shall include any available corrective action, either automatic or provided by an operator of the equipment; the results of that action; and an indication of the resulting degree of equipment degradation. All fail-safe features will be listed.

(g) Probability of Occurrence - The probability of occurrence is a numerical value denoting the likelihood that the assumed failure could be experienced. Safety margins between strengths and stresses, and derating factors at pertinent temperatures will also be indicated, as appropriate. These latter factors will be based on circuit and stress analyses which include the consideration of applied environmental, mechanical, and electrical loads, strength of materials and load distribution.

(h) Remarks - Any statement will be provided which would augment or clarify the information of the preceding paragraphs.

(i) Failure Classification - Failure classifications separates the assumed failures into categories for the purpose of providing a comparative key to gravity of the failure. Failures will be classified as follows:

Criticality I — Failures resulting in immediate loss of crew, as for example, tank explosions or failures resulting in subjecting the crew to conditions beyond emergency limits. Failures in this class cannot be compensated for with existing backup equipment or operational procedures.

<u>Criticality II</u> Failures in this class may not be catastrophic if a successful abort can be accomplished. Mission abort would result from Class II failures through established abort paths defined for each mission phase and equipment state.

<u>Criticality III</u> Failures which would warrant an abort during a particular phase because continuing with mission would reduce chance of crew safety.

<u>Criticality IV</u> Failures in this class are considered nuisance type failures and not serious enough to cause mission abort. Failures can generally be corrected or compensated for by crew action.

LEM MAINTAINABILITY

3.3.1.6 Maintainability Analysis - An analysis will be conducted to determine the need, degree and amount of inflight maintenance that can be successfully performed on the LEM. Maintenance will be limited to those equipments which are critical to the operation of the LEM, physical well being of the' occupants of the LEM and which can be maintained either on the moon or in space. A schedule for replacement of limited life items and recommendations for spares during the mission will be included in the maintainability analysis.

See also the LEM Maintenance Plan.

3.3.1.7 Parts Application & Standardization

All available pertinent data and information on component parts, including effects of environmental and electrical stressing will be utilized wherever practicable. Reference will be made to the Interservice Data Exchange Program files and other reports as obtainable for guidance in evaluating parts considered for use in the LEM.

Military parts included in specifications MIL-STD-242 and MIL-E-5400 will represent a minimum in quality.

All parts used in any equipment for LEM whether at Grumman or at vendors will be subject to the advance approval of Grumman, Parts Evaluation Group in the Reliability Section. Such approval would be based upon the best available information, drawing upon the above-referenced sources and other relevant material.

In addition to the use of approved component parts, the designers will be obliged to de-rate the parts and apply them in circuits and functions meeting advanced approval. Thus, part application as well as part selection shall be subject to reliability approval.

3.3.1.7 Lem Maintainability (Continued)

The use of "high-reliability" parts such as Minuteman, etc. will be considered. Use of non-standard parts shall not be approved by GAEC unless:

1) Standard parts adequate for the specific application do not exist, and

2) evidence satsifactory to Grumman reliability is produced to substantiate the adequacy of the non-standard part in both performance and reliability for the specific application.,

3.3.1.7.1 Acceptable Parts Listing- Grumman will prepare a LEM Acceptable Parts List which will include "qualified" parts, selected limited-life items, and parts considered acceptable without formal qualification. The latter parts will be adjudged acceptable by virtue of adequate history and/or results of pertinent previous testing. Qualification testing will be required only in certain cases wherein a definite need for a part exists in the absence of sufficient information to form a sound engineering judgment.

3.3.1.7.2 Parts Improvement- Improvements in the reliability of parts through modifications in design, processing and inspection/testing will be sought wherever practicable as a by-product of the LEM parts control program. Data obtained in the course of the parts program may suggest, through analysis, possible improvements by the above types of modifications. Proposals to GAEC for improvements by the parts manufacturer would then follow. The degree of cooperativeness of the manufacturer would influence the amount of LEM business he obtains.

3.3.1.8 Reliability Estimates- All phases of the design effort will be monitored and up-to-date estimates of the reliability of all items of equipment and components will be maintained. Reliability estimates of electronic equipment will be prepared in accordance with the procedures established in MIL-STD-756 (WEPS)

3.3.1.8 Reliability Estimates- (continued)

Environmental usage factors will be determined on the basis of empirical data. Reliability estimates for electronic equipment will be based on the failure rates listed in MIL-HDBK-217 except that other failure rates based on carefully selected parts and special handling and manufacturing procedures will be used. All failure rates derived from sources other than (MIL-HDBK-217) 8 August 1962.) will be listed in the same units and will refer to the same performance and environmental conditions as the failure rates appearing in MIL-HDBK-217. All failure rates regardless of their source, will apply to parts which will be used in the delivered product. Reliability estimates for non-electrical equipment or components will be based on failure rates subject to NASA approval.

Periodic status reports will be submitted to NASA comparing the reliability estimates with the apportioned reliability requirements, and pointing out anticipated or potential trouble areas.

Whenever the reliability estimates of any given item of equipment or component is deficient with respect to the apportioned reliability goal, the goal will be re-examined and if it cannot be reduced, the equipment or component will be redesigned so that its reliability equals or exceeds the specified objective. First estimates will therefore be made as early as possible during the design stage in order to allow sufficient time before design freeze or redesign as necessary.

All reliability estimates made subsequent to the circuit analysis (para. 3.2.4.2) will be based on derating factors, failure modes and effects, and circuit failure probabilities derived in the circuit analyses.

3.3.2 Surveillance of Test Program .- The test program will demonstrate that the reliability and maintainability of all delivered hardware and equipment complies with all specified requirements. Close surveillance will be maintained over the equipment or subsystem development, qualification and

3.3.2 (Surveillance of Test Program)(Continued)

acceptance testing program to assure that tests will yield a maximum of information and provide a high degree of confidence that the minimum reliability and maintainability objectives are achieved. All development qualification and acceptance detailed test plans will consider the requirements for providing reliability data. Since the length of testing time available is small in relation to the required reliability and confidence levels desired, it becomes mandatory that the fullest possible use be made to generalize test results as much as possible by planning tests and evaluating results from the viewpoint that they should confirm analytical procedures and demonstrate the validity of the design assumptions. No test will be run until all hardware parameters which at the present state of the art can be established by analytical procedures. Test plans will distinguish between parameters established by analytical procedures and those established empirically or by cut-and-try methods. Test plans will list the parameters established by analytical procedures and reference the documents in which these parameters are established. The test program will consist basically of component tests and system tests. Component tests are primarily tests-to-failure whose purpose is to determine the performance and strength of the component under a judiciously selected combination of systematically increasing environments representative of the operating environment. System tests are tests of assemblies of two or more components to determine the effects of interactions on the operating environments to determine the effects of interactions on the operating environments of the components and to verify that the actual peak combined operating environments on the components do not absorb the specified margins of safety and reduce the reliability below the required level.

3.3.2.1 Test Identification - All test plans will be received by reliability systems personnel in order to determine whether data applicable to reliability analyses may be generated, or whether some modification of the test plan might yield more meaningful results. In addition, if the hardware under test is near flight weight.configuration or has a direct bearing on the final configuration failure reports will be requested.

3.3.2.1 Test Identification- Continued-

The critical test parameter and environments to be sustained and other related facts will be placed on an IBM card. A "Test Identity" number will be assigned to the test so that the pertinent facts of the test may be traced through the component which was tested. These cards will be updated to include the results of the tests so as to provide a total case history. The test I.D. program will supply valuable failure mode information to engineers when malfunctions are detected during the systems tests and flight development program. A by-product of this program will be to allow Grumman to pool the results of similar test programs being run by vendors, or in some cases eliminate the duplication of effort if desired.

3.3.3 Failure Reporting and Analysis System- An overall failure reporting system will be established to' collect, analyze, and disseminate failure mode data and operating time data generated from tests at operation at Grumman and vendor facilities. The system will include provisions for malfunction review, diagnostic testing and corrective action to eliminate or materially reduce the probability of recurrence. The failure reporting and analysis system will be effective during development, qualification, and acceptance testing as well as ground operations and flight test.

3.3.3.1 Reporting Forms- Failure reports will be made on forms which are being designed for machine processing.

3.3.3.2 Analysis of Failures- All failures reported on the form of paragraph 3.3.3.1 will be analyzed to determine the cause, failure classification, and corrective action required. Consideration will be given to all applicable methods of diagnosis, including analysis studies, test, X-rays, dissection, chemical analysis, etc. Results of the analysis will be included on the reporting form and on the Failure reporting and analysis monthly run-off for failures that occur during the development tests, Results of the analyses of failures that occur during qualification and acceptance testing will be submitted as completed.

3.3.4 Vendor Control - The vendor reliability requirements are being incorporated in the Design Sepcifications and the Vendor Requirements Documents. The following sections of these documents reflect the requirements.

a. Requirements- Design Specification LSP

1. Paragraph 3. X- Reliability-Numerical Goal (see Appendix A for example)

2. Paragraph 4.4.X- Reliability Assurance (see Appendix A for example)

3. Table II- Environmental and Load Conditions (See Appendix A for example)

4. Table IV Typical Engine Life Cycle

b. Tasks- Vendor Requirement Document- LVR-xxx-x

1. Section C- (see appendix A for example)

c. Special Provisions- Vendor Requirement Document LVR-xxx-x

1. Section D (see appendix A)

d. Documentation- Vendor Requirement Document LVR-xxx-x

1. Section E (see appendix A)

e. Instructions For Preparation of Proposal Vendor Requirement Document LVR-xxx-x

1. Section G- (See Appendix A)

[redacted]

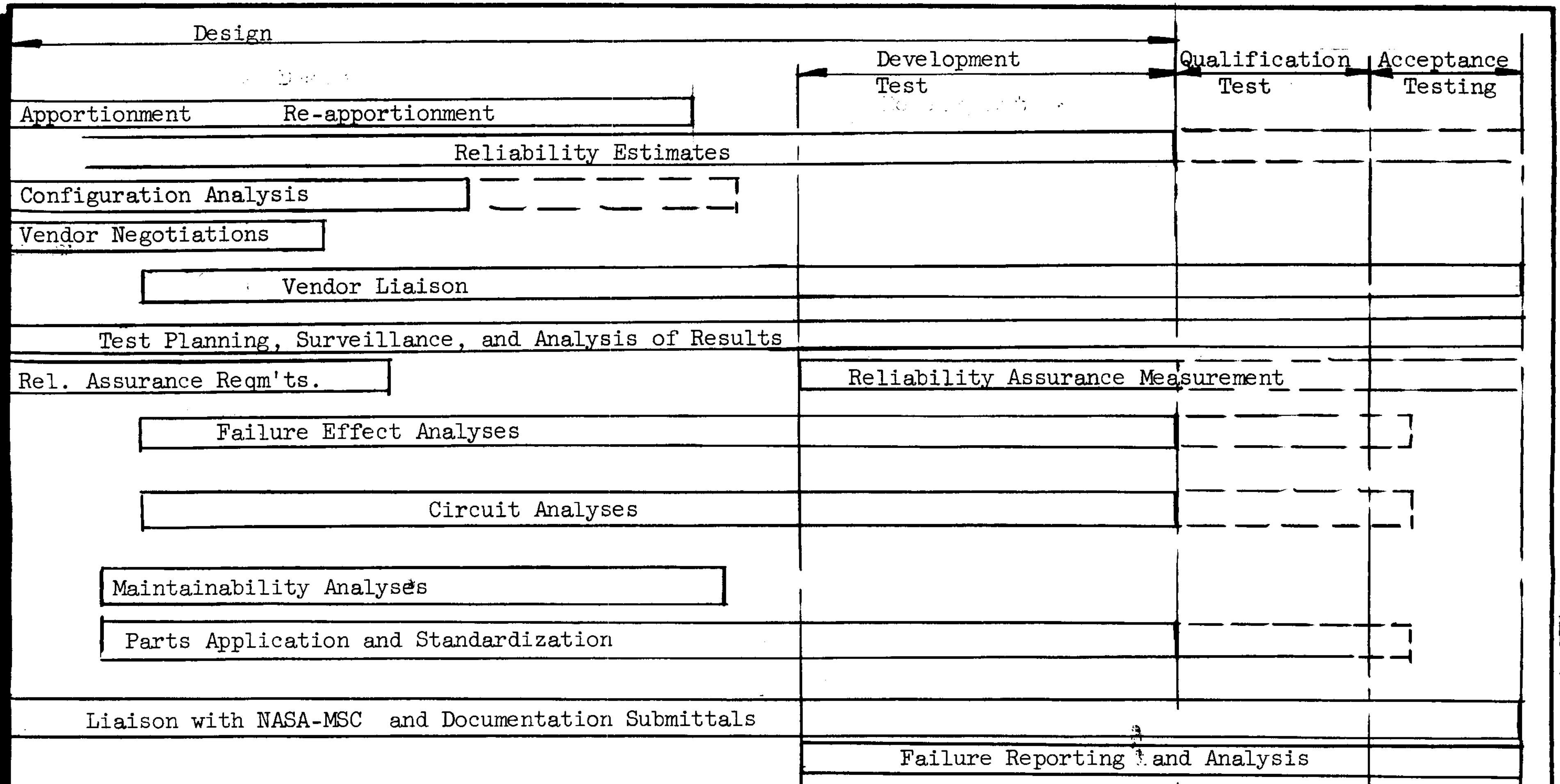


FIGURE 3-1

PHASING OF LEM RELIABILITY ACTIVITIES

SECTION 4

RELIABILITY ASSESSMENT OF TEST PROGRAM

4.1 The basic purpose of the Grumman Test Program is to assure that the LEM will meet the objectives defined in the NASA work statement which requires that: "the attainment of the maximum mission reliability and crew safety shall be the most important single considerations in the design, construction, handling, and operation of the Spacecraft."

4.2 TEST PROGRAM OBJECTIVES

As a partial fulfillment of that objective the LEM Test Program has been designed to provide a practical maximum of engineering and statistical confidence in the ability of the LEM equipment to perform in a satisfactory manner for the lunar mission. The Test Program Objectives are outlined as follows:

A - Verify the integrity of the design

B - Provide a known margin of strength in the product

C - Design test programs to yield maximum information as early in the program as possible.

D - Place emphasis on Ground Test Program to reduce likelyhood of costly failures in the flight test program.

4.3 BASIC PRINCIPLES

To accomplish these objectives certain basic principles must be observed throughout the conduct of the entire test program. These principles dictate that each test contribute knowledge, which significantly advances the progress of the program not only in a qualitative but a quantitative manner. These principles briefly stated are:

1 - Maximum usage must be made of all test programs to verify design margins, seek out "weakest link" failure modes, and make a measurement of the minimum reliability of the equipment with some statistical confidence.

2 - The Test-To-Failure will be the basic tool in the program to achieve the objectives expressed in (1).

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BASIC PRINCIPLES (Cont'd)

3 - Qualification tests will be run at levels of severity greater than maximum mission design levels. Where practical, Qualification tests will be run at the highest level of assembly deliverable. Tests run at the component level are intended to reduce the likelihood of untimely redesign at a later stage in the development program. Development and qualification tests will be used to evaluate the acceptance test procedures.

4 - Test programs will be conducted on components as a minimum level of assembly. Elemental parts will be scrutinized by Grumman parts control such that only selective testing will be necessary.

5 - A measurement of the minimum reliability shall be a prerequisite of Qualification. This will be implemented to the extent possible within the program and schedule constraints.

6 - Acceptance tests will be performed on deliverable items to those levels of the environmental and performance parameter severities that were established as significant for screening marginal items during the development and qualification test programs. This will be done in order that assurance is obtained that this equipment is fully representative of the qualification equipment.

7 - Test Program emphasis shall be placed on safety of flight items.

8 - Test results on common usage items shall be pooled to minimize the extent of the test program and reduce hardware requirements.

4.4 RELIABILITY TEST PHILOSOPHY FOR LEM

4.4.1 LEM RELIABILITY OBJECTIVES

The LEM reliability objectives of .984 for Mission Success and .9995 for Crew Safety are possibly the most stringent targets ever set for a system of the magnitude and complexity of the LEM. In addition the mission requirements of LEM are at the edge of the state-of-the-art.

As a design objective, LEM's reliability goal will strain the tools of design and reliability analysis to the utmost. To demonstrate the LEM reliability goal is beyond the scope of schedule and dollars allocated for the program. Therefore, as a practical measure, a method of screening unreliable equipment from use on the LEM will be employed in the form of the variables stress test-to-failure.

LEM RELIABILITY OBJECTIVES (Cont'd)

These tests will provide the basis for the LEM Reliability Assurance Test Program.

4.4.2 STRESS TO FAILURE TEST

The stress-to-failure test will be utilized in two ways for the LEM program. First, it will provide a basic design tool during the early portions of the development program. Secondly, it will be employed as a reliability assurance tool once the development program has progressed to the design freeze phase.

As a design tool the stress-to-failure test:

A - Verifies equipment strength margins.

B - Identifies weakest link failure modes

C - Verifies assumptions made in reliability analysis

D - Provides quantitative as well as qualitative information for the design effort

As a tool for reliability assurance the stress-to-failure test:

A - Provides a measurement of the equipment strength margin at a selected high statistical confidence.

B - Requires considerably less hardware than classical reliability demonstration tests such as the attributes test.

C - Is geared to the tight schedule requirements of LEM because of its very nature.

D - Run on components and sections, the stress-to-failure test should reduce problem areas on the subsystem level development and qualification tests to interaction and interface problems.

E - Probes in the direction of least knowledge. By this is meant that, by demonstrating equipment strength margins, information is gained in the region which has traditionally plagued engineers. Experience has shown that a major portion of equipment failures are traceable to an underestimate of the actual mission environments. Thus, the stress-to-failure test exhibits a decided advantage over repeated mission simulation (attributes) testing by providing continuous scale data points for the equipment. In contrast, the repeated mission simulation test, ignoring to a large extent the possibility of environmental underestimates, probes in the direction of time which is the one parameter which is in fairly good control prior to the start of the flight. Mission time is limited by factors such as rocket propellant consumption, fuel cell reactant supply consumption, mission abort criteria and mission completion.

4.4.2.1 STRESS-TO-FAILURE TEST DESIGN TOOL

In keeping with the stated principles that all testing must yield a maximum of information to aid in design evaluation, LEM components and sections will be required to be tested to failure to provide basic information for the design and aid in reliability analysis by supplying failure mode information. Even at the breadboard stage, elements and components will be subjected to conditions such as extreme temperatures to determine the maximum tolerance of the basic components to the predicted environments. An attempt will be made to "wring out" the design before the program progresses into more advanced stages.

STRESS-TO-FAILURE TEST DESIGN TOOL (Cont'd)

All development tests will be listed with the Reliability Control Section in order that program surviellance can be maintained. Failure reports will be filed to provide a check against incomplete investigations of any unforeseen or unaccountable failure modes or trends to determine the causes and their possible effect on the reliability of the design.

4.4.2.2 STRESS-TO-FAILURE TEST FOR RELIABILITY ASSURANCE

One of the basic producers of unreliability in a product is the variability of strength which may exist from one sample to the next. Conceivably, an equipment design can be flawless from the standpoint of its ability to perform on paper all of its intended functions. However, experience has shown that many a selected design has failed to come up to expectations once placed into production or subjected to actual operating conditions. The cause of the problem can usually be traced either to equipment strength which varies from the acceptable to the unacceptable or to improper evaluation of the operating conditions during the design phase. If the latter occurs for the LEM mission it may never be detected because of its obvious consequences.

However, a mission as critical and costly as LEM's should not allow poor quality to become a hindrance to success.

The very nature of equipment strength variability renders the classical qualification test of one or two equipments ineffective as a screening tool. The LEM Reliability Assurance test program is designed to provide some statistical confidence that the LEM equipment will not fail due to strength variations which are traceable to:

a - Material inconsistencies

b - Dimensional, or tolerance variation

c - Structural response and stiffness variation

d - Workmanship problems

Therefore, the stress-to-failure test as applied during the reliability assurance test, will demonstrate the equipment strength margin with allowance for the equipment variation. This margin should provide additional engineering confidence in the ability of the equipment to perform adequately, even though the environments may have been underestimated in the design stage.

4.4.2.2.1 RELIABILITY ASSURANCE REQUIREMENTS

In applying the stress-to-failure test as a reliability assurance tool, certain conservatisms are built into the test procedure which make it an effective screen against marginal equipment.

The basic requirement is presented here in the general format which appears in the Design Control Specification for vendors.

4.4.2.2.1.1 DEMONSTRATION REQUIREMENT

The results of the stress-to-failure test shall show that the probability of occurrence of a failure at or below the Reliability Boundary (RB) shall be no more than 5%. This statement shall be made with a statistical confidence of 90%.

This requirement shall be fulfilled as a prerequisite to the start of formal qualification tests on the individual component or section involved.

4.4.2.2.1.2 RELIABILITY BOUNDARY

The Reliability Boundary is the upper bound of the "operating rectangle" as shown in Fig. 4.1 generally the RB will be more severe than the maximum expected mission environments but less stringent than Grumman Qualification test levels. Two methods proposed for establishing the RB are:

A. From reliable empirical data - the RB is selected as the peak value of environment which has a 99% probability of not being exceeded in the mission.

B. By Sound Engineering Judgment - When the empirical data available is insufficient or unacceptable for adequate definition of the pertinent conditions and operating parameters of the Reliability Boundary, these conditions will be established by the vendor as conservative margins above the maximum expected environmental and dynamic conditions for the LEM pre launch, launch, translunar, and lunar mission. Operating parameters will be treated in the same manner. These conditions will be submitted to Grumman in the Reliability Test Plan.

In proposing Reliability Boundary conditions Vendors will consider margins in the order of 1.15 for dynamic loads and ± 15°F for thermal environments. The Reliability Boundary Conditions of other earth space, and lunar environments will contain similar margins. In general, Reliability Boundary Conditions will be less severe than Qualification Test levels.

STRESS-TO-FAILURE AS APPLIED TO LEM

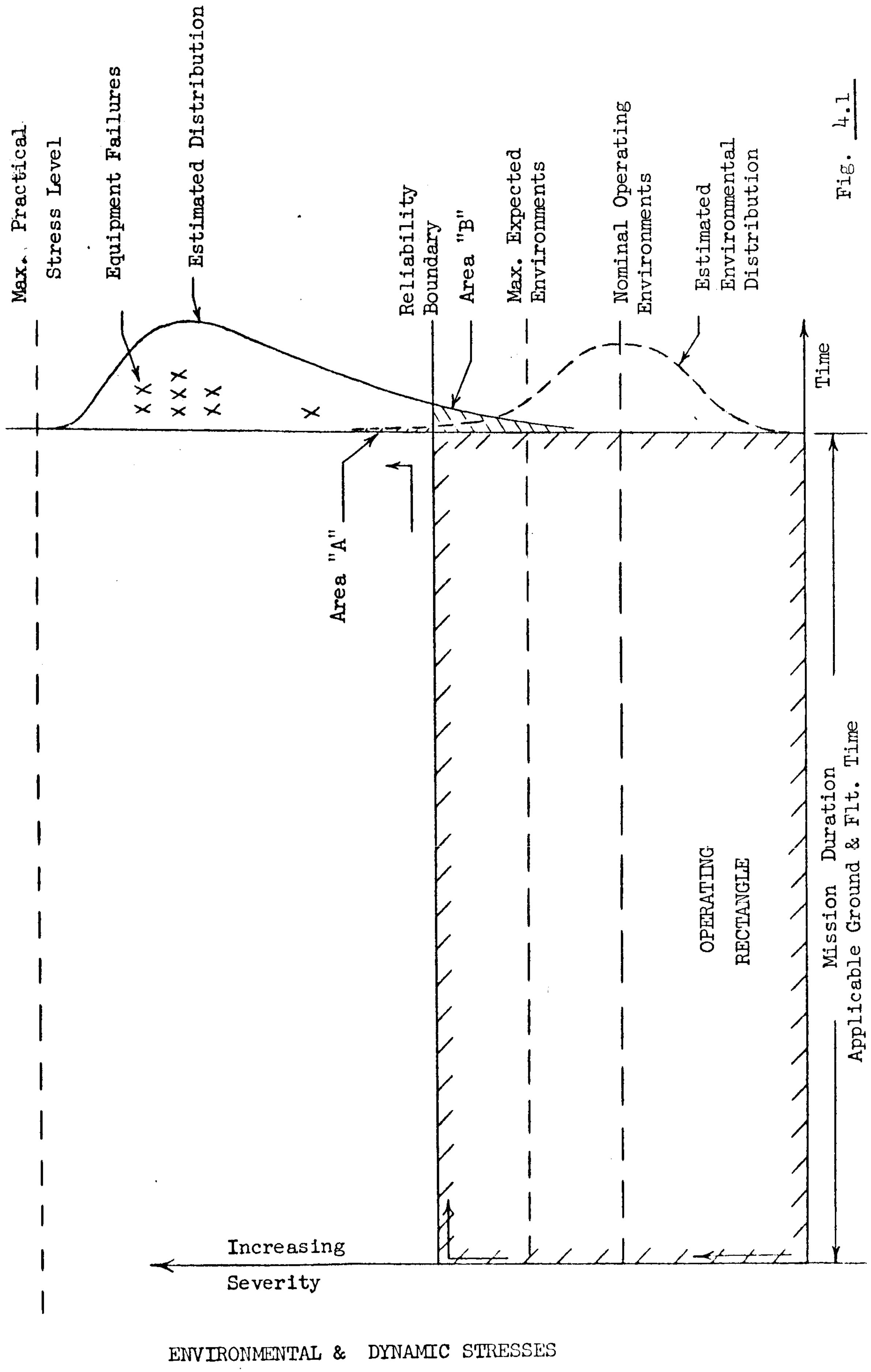


Fig. 4.1

Reliability Boundary Conditions should be sufficiently representative of the mission profile to uncover failure modes predicted for the stress to failure portion of the test.

Table 4-I is provided as an illustration of the level of severity for the environmental conditions of the RB. This table will be updated as necessary.

4.4.3 RELIABILITY TEST HARDWARE

Tests applicable to reliability assurance will be run on flight weight hardware. The quantity of hardware required for reliability assurance will be proposed by the vendor. However, in preparing his hardware utilization program, the vendor will consider that by careful planning these requirements can be met in the normal fulfillment of the component development and qualification test programs. The following factors will be considered in proposing the number and nature of tests:

a) In the stress-to-failure test, seven occurrences of the same failure mode for each test component, or a maximum of ten failures of any mode for the equipment will be sufficient for analysis.

b) If the failure mode anticipated during these tests is not completely destructive, a minimum of two components will be tested to satisfy the reliability assurance requirements. Repairs or refurbishment will permit reuse of the component for further testing.

4.4.4 ANALYSIS OF RESULTS

The Weibull analysis technique is the procedure recommended for application to the results of the stress-to-failure test. (Ref. paragraph 4.5.2. of this report)

Alternate methods of analysis may be proposed by vendors to achieve the same result. These methods are to be submitted to Grumman for approval as part of the Reliability Assurance Test Plan for the specific equipment involved.

The underlying assumptions and mathematical derivations involved will be presented in detail. However, until alternate methods are approved, vendors will proceed under the assumption that the Weibull techniques will be employed.

TABLE 4-I

GUIDELINES FOR RELIABILITY BOUNDARY CONDITIONS

TEST DESCRIPTION	INTENSITY OR RATE	CYCLES OR TIME	REMARKS
1. ACCEPTANCE			To be conducted in accordance with the Acceptance Test Procedures
2. PRE-LAUNCH AND GROUND SUPPORT			
2.1 TEMPERATURE	Limits as specified in the qual. levels except that intensities shall be reduced by 10° F.	To be supplied.	
2.2 Humidity	To be conducted in accordance with MIL-STD-810 (USAF)	Method 507 Max. time of 4 days	
2.3 VIBRATION ITEMS TO 100 LBS	0.36 IN.D.A. ±1.0 g 0.03 IN.D.A. ±4.0 g	5 - 7.2 cps 7.2 - 26 cps 26 - 52 cps 52 - 500 cps	Test item in container. Vibration shall be applied along 3 mutually perpendicular axis. Frequency shall be swept at $\frac{1}{2}$ octave/min. Total time to be supplied.
ITEMS 100 TO 300 LBS	Use Figure 514-8 Method D'T'D 14 June 62 for max	514 MIL-STD 810 (USAF) cps	
ITEMS OVER 300 LBS	0.5 IN.D.A. ±1.3 g 0.04 IN.D.A.	5 - 7.2 cps 7.2 - 26 cps 26 - 52 cps	

TABLE 4-I
GUIDELINES FOR RELIABILITY BOUNDARY CONDITIONS

TEST DESCRIPTION	INTENSITY OR RATE	CYCLES OR TIME	REMARKS
2.5 - GROUND SUPPORT ENVIRONMENTS (RAIN, R.F.I, SAND, FUNGUS, ETC.)	Vender shall analize effects of environments specified in Table Ia of the Design Control Specification Equipment. Environments which are critical or deleterious to the reliability of the equipment shall be simulated at Qual levels, or if not specified, at limits given in Table Ia.		
3. LAUNCH			
3.1 VIBRATION - TEMP. 3.1.1 RANDOM	Linear Increase from .003 to .02 g^2 /cps Constant .02 g^2 /cps Linear decrease to .004 g^2/cps	5 - 50 cps 50 - 150 cps 150 - 2000 cps	Vibration shall be 17 min. for each of the 3 mutually perpendicular axis.
3.1.2 TEMP.	Class I +165° F Class II +165° F Class III +105° F Class IV +105° F	Exposure for duration of vibration test	High temperature only, temp as specified or at qual levels for launch less 10° F, whichever is lower.
3.1.3 RANDOM (SPACE)	.006 g^2 /cps Linear Increase to .03 g^2/cps Constant .03 g^2/cps Linear Decrease to .012 g^2/cps	- - 5 cps 5 - 100 cps 100 - 200 cps 200 - 2000 cps	Vibration shall be 6 min. for each of the 3 mutually perp. axis.
3.1.4 TEMP (SPACE)	Temp. as specified in space qual. levels except that intensities shall be reduced by 10° F.	Exposure for duration of vibration test.	High temperature only

TABLE 4-I

GUIDELINES FOR RELIABILITY BOUNDARY CONDITIONS

TEST DESCRIPTION	INTENSITY OR RATE	CYCLES OR TIME	REMARKS
3.2 ACCELERATION CONDITION (A) CONDITION (B)	X: +6.5 g, -1.7 g; Y & Z: $\pm$2.0 g	Exposure for 5 min per direction.	
4. SPACE FLIGHT			
4.1 THERMAL VACUUM	Pressure at 1×10^{-5} or lower. Thermal as specified in the Qual. levels except that temp. intensities shall be reduced by 10°F. Solar Radiation, 440 BTU/ft^2 hr, Class IV equipment only where applicable.	Exposure for 80 hours for Class I equipment. Exposure for 160 hours for Class II, III, and IV. Apportioned time at each exposure shall be equal.	Equipment duty cycle and temps. to be simulated during thermal vacuum an O_2 shall include space flight, lunar descent lunar stay and lunar ascent.
4.2 O_2 EXPOSURE (CLASS I EQUIPMENT)	O_2 atmosphere at 75% rel. humidity. Pressure at 1 ATM. Temp. as specified in Qual. level except that temp. shall be reduced by 10° F.	Exposure for 80 hours.	High temp. only.
4.3 HARD VACUUM	Pressure less than 1×10^{-9} mm hg	Duration as specified in 4.1.	For critical components and mech'l subass'ys which are suceptable to hard vacuum induced failures. Selection based upon Eng. Analysis or development data.

TABLE 4-I
GUIDELINES FOR RELIABILITY BOUNDARY CONDITIONS

TEST DESCRIPTION	INTENSITY OR RATE	CYCLES OR TIME	REMARKS
5. LUNAR			
5.1 VIBRATION - TEMP 5.1.1 RANDOM 5.1.2 TEMP.	.0067 g^2/cps Linear Increase to .056 g^2/cps Constant .056 g^2/cps Linear Decrease to .039 Temp. as specified in 4.1	- - 5 cps 5 - 100 cps 100 - 1000 cps 1000 - 2000 cps Exposure for duration of test.	Vibration shall be 20 min. for each of the 3 mutually perp. axis, except that equipment located in the descent stage shall be vibrated for 12.min. along each axis. High temp. only.
5.2 SHOCK	To be supplied.		

NOTE: CLASSIFICATION OF EQUIPMENT ACCORDING TO ITS LOCATION IN THE LEM CONFIGURATION FOR USE IN THIS APPENDIX.

EQUIPMENT LOCATION	CLASSIFICATION
Cabin	Class I
Equipment Bay	Class II
Propulsion Compartment	Class III
External Surface of LEM	Class IV

4.4.4.1 BUILT IN CONSERVATISM

While no statistical statement can be made about the probability of a deleterious environment actually occurring at or just below the reliability boundary, engineering judgment can show intuitively that any equipment that successfully passes the minimum demonstration requirement actually has a considerably greater probability of success for the LEM mission.

For instance, if the probability (Pe) of encountering during the mission an environment (or combination of environments) as severe as the R.B. conditions is, say, .01, and the probability of having a failure at that stress level (P_{FS}) is no greater than .05, given that The RB conditions are encountered, then the probability of failure for the equipment in the actual LEM mission (P_{FM}) may be expressed as:

$$P_{FM} = P_e \cdot P_{FS/e} = .01 \times .05 = .0005 \quad (1)$$

Therefore, the probability of success for the actual mission may be expressed as .9995. Without attaching rigid mathematical significance to this judgment, the conservatism in the approach is apparent. In addition, the equipment will be subjected to its R.B. conditions for one mission cycle during its test, rather than the nominal conditions it is likely to encounter in the actual mission.

4.4.5 CURTAILED TEST CRITERIA

While the primary objective of the reliability assurance test is to determine the strength margin of the equipment while taking into account equipment variability, it is expected that some hardware will exhibit margins of safety which are of such magnitude as to be capable of verification after as few as two or three failures are encountered under the increasing stresses. According, the failures will be analyzed and plotted progressively after each failure, so that the test can be truncated as soon as the minimum reliability requirements have been met.

4.4.6 RELIABILITY ASSURANCE PLANNING

A detailed test plan shall be required of all vendors or Grumman engineers performing reliability assurance tests.

This plan shall include, but not be limited to:

(a) Purpose of test - (Reliability Assurance or otherwise).

(b) Description of Test Specimen.

(c) The test conditions and; operating parameters selected for the Reliability Boundary (RB). The basis for this selection, and the method of application.

(d) The applicable "mission time" for the test.

(e) The critical stresses and operating parameters chosen for stress testing to failure and the reasons for the selection.

(f) The maximum practical stress level and the increments (% above RB) chosen for the stress test to failure.

(g) The predicted failure mode.

(h) The analysis techniques to be employed to show compliance with Reliability Assurance requirements.

(i) The environmental stress level for establishing a curtailed test criteria (See Paragraph 4.4.5)

4.5 PRACTICAL APPLICATION OF STRESS-TO-FAILURE TESTS TO THE LEM TEST PROGRAM

4.5.1 PROCEDURE FOR SETTING UP TEST

The Reliability Assurance tests are conducted at selected levels of assembly and consists of three phases; the pre-test run-in, the stress-to-failure test, and statistical analysis of the test failure distribution. Each test series is so designed as to yield the most accurate and pertinent data required for assessing:

(i) The inherent strength margin;

(ii) The variability of the test units strength margin from test-to-test;

(iii) The variability of the equipment's strength margin from test unit to test unit; and

(iv) The probability of failure at a specified level of stress (The Reliability Boundary).

4.5.1.1 THE OPERATING RECTANGLE

Prior to the stress-to-failure tests, the samples are aged by subjecting them to a run-in represented by the "operating rectangle." (Ref. Fig. 4.1). The operating rectangle is established by the two operational parameters, stress and time, which are, in turn, based upon the stress-duration histories specified in the LEM mission profile.

Of the two parameters, only the run-in time is known to any degree of accuracy. It will include, in addition to the actual mission time, operating time experienced prior to launch, such as that accumulated during acceptance tests and pre-launch operations.

The stress levels expected during the LEM mission are not accurately known. They are the best predictions that can be made from experience and theory, but may, as in previous spacecraft missions, be an underestimate of the conditions to which the LEM will actually be exposed. For this reason, the levels of stress to which the samples will be subjected during the run-in will be somewhat higher than those predicted. (Ref. Table 4-I) These levels, represented by the Reliability Boundary conditions, in the operating rectangle, are discussed under "Demonstration Requirements" of this section.

4.5.1.2 SELECTION OF STRESSES FOR RELIABILITY BOUNDARY

In order to simplify the test operation wherever possible, consideration will be given to omitting any stress, or combination of stress, which can be shown, by analysis or through previous experience, to have a trivial affect on the equipment's life or performance.

When test facility limitations or state-of-the-art considerations eliminate the possibility of applying a specific group of stresses simultaneously, each stress, as required will be applied by itself sequentially.

Vibration conditions will be imposed in the three primary orthogonal directions, each direction being held or repeated for equivalent mission times. This approach is taken with the assumption that most equipment will possess a minimum of cross coupling between the primary directional modes. Equipment which does not exhibit this effect (as determined from a preliminary search) may necessitate some reduction in real time to eliminate overtesting.

Wherever practical, environments which are known to have interacting effects on the test specimen and which are naturally combined in the LEM mission, should be combined in the Reliability Assurance Test.

4.5.1.3 STRESS INCREMENTS IN THE STRESS-TO-FAILURE TEST

At the completion of the operating rectangle, the stress levels will be increased in percentage increments over the Reliability Boundary such that there will exist seven (7) to ten (10) increments between the Reliability Boundary and the maximum practical stress level. This is the level above which the equipment will not be stressed - due to material limitations, chemical instability, test equipment limitations, etc. In the case where time or cycles in a critical parameter, these parameters shall be included in combination with the other critical stress conditions in the stress-to-failure.

The manner of increasing the stress levels is shown graphically in Figure 4.2.

Each selected stress or combination of stresses is applied, in turn as required, to the specimen before being advanced to the next level of severity. This procedure is continued until the specimen fails, where failure is defined to be any degradation in performance beyond the minimum acceptable operating mode.

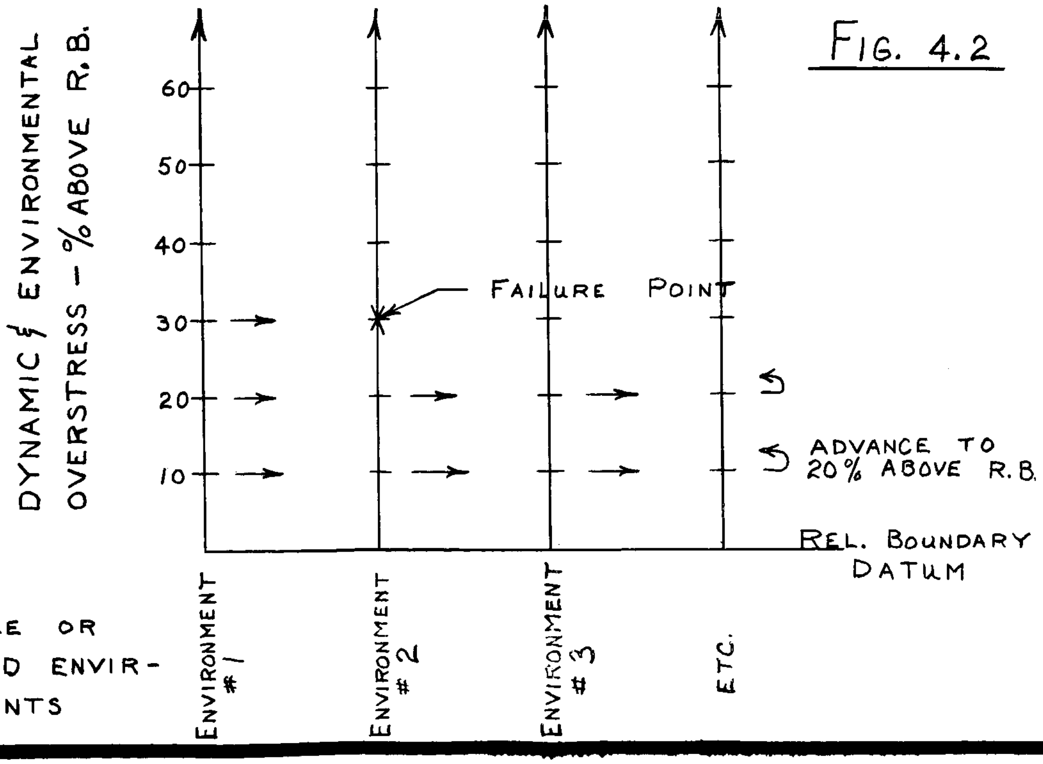


FIG. 4.2

4.5.1.4 TREATMENT OF FAILURES

When a specimen fails during the stress-to-failure test, the stresses are removed, and the causes of the failure are determined for the purposes of recording the necessary data for correlation with the Failure Mode Prediction. This failure will also be utilized to show compliance with reliability assurance requirements.

If the failure mode does not concur with that predicted, the designer must furnish adequate reasons for this discrepancy.

The number of failures required for statistical analysis will depend on the trend which is evident in the first few failure points. Conceivably, as few as two or three will suffice if the failures are well "bunched" at a stress considerably above the Reliability Boundary. (Ref. Para. 4.4.5). A maximum of ten has been established as yielding the most contribution to the statistical analysis for the lowest dollar.

If possible, the specimen can be repaired or refurbished with a new piece of hardware and placed back on test to gain additional information as to secondary failure modes etc. Significantly, further failures on a refurbished test specimen cannot be utilized to reinforce the statistical analysis of the failure because of the confounding effect of the new stress.

In a number of cases, as often happens when the failure is a degradation in performance, the test unit (component made of multiple parts) will recover following removal of the stress. It is possible, therefore, to accumulate seven to ten failure points using only one test unit. However, since the reliability assurance stress-to-failure tests are designed to assess the strength variability among test units, a minimum of two units is specified.

4.5.2 ANALYSIS TECHNIQUE

4.5.2.1 WEIBULL ANALYSIS

Most of the techniques currently utilized for evaluation of equipment reliability would, if applied to the LEM program, necessitate the expenditure of a prohibitive quantity of equipments and money. They require, in addition, the assumption of an underlying distribution of equipment failures which (1) does not have the ability to describe a variety of failure rate patterns, (2) cannot describe changes in the equipment failure rate patterns, and (3) is difficult to handle analytically.

However, an analysis technique based upon the assumption of the three-parameter Weibull distribution as the underlying distribution of equipment failures is not subject to the restrictions described above.

For failure analysis, the basic mathematical model of the Weibull distribution is expressed in the form:

$$F\,(x) = 1 - e^{\frac{(X)^m}{\theta}} \qquad 1 - e^{\frac{-(X - Xo)^m}{(\theta - Xo)}}$$

where F (x) = Percent that have failed at and below a life or stress equal to x.

X = Observed life or stress at the last failure involved in expressing F(X).

θ = "Characteristic Life" = life or stress whose accumulated probability of previous failure,

F (θ) = 0.632; A constant for a given fitted Weibull Distribution.

m = Weibull Slope - A second constant which will produce a function that will best fit the distribution being studied.

The third parameter is the amount and direction of the shift of the life or stress scale to bring the origin of the Weibull Distribution to X = 0 at Xo.

4.5.2.2 PROPERTIES

The specific properties of the Weibull distribution which combine to warrant its employment as an analysis technique for Reliability Assurance testing in the LEM program are:

(1) Flexibility - The Weibull distribution contains parameters (m, θ, X_o) which make the Weibull an infinite family of distributions. Many of these distributions have been shown to be of considerable value in describing various equipment life patterns. The commonly used exponential is a special case of the Weibull ($m = 1.00$), and the normal of Gaussian distribution is closely approximated by the Weibull ($m = 3.25$). In addition, the Weibull distribution can describe changing failure rate patterns, such as the famous bathtub curve, which indicates periods of decreasing, constant, and increasing failure rate. It has also been shown that the Weibull distribution provides a good fit to failure observations in many widely varying load profile fields.

(2) Economy - Investigations have shown that relatively smaller amounts of additional information are gained from each succeeding failure. When the cost of testing each additional unit is considered along with the cost of providing larger factors of safety it appears that about seven failures is a reasonable number of failures to use for the Weibull analysis.

(3) Simplicity - The analysis of the test results and the decision to accept or reject the equipment can be made on the basis of a graphical plot of the cumulative number of failures and a 90% lower confidence band,* once the accept-reject criterion is established. This graphical procedure is extremely simple and easy to handle.

(4) Theoretical - The form of the Weibull cumulative distribution function coincides with the form of the cumulative distribution function of a general failure model.

4.5.2.3 WEIBULL ANALYSIS PROCEDURES (GRAPHIC)

The procedure for analyzing by the Weibull analysis technique, the reliability assurance test failure data is as follows:

* This can be done with the Standard Weibull, attribute method; or even less conservatively with a variables, lower statistical confidence limit position of a normalized Weibull Distribution.

4.5.2.3.1 Each failure is noted and assigned a number indicating its position in the failure sequence (e.g., 1 = first failure occurring in sample. 2 = second failure occurring in sample, etc.).

4.5.2.3.2 On a piece of Weibull probability paper, draw a line parallel to the percent failure ordinate and label it the Reliability Boundary. Label the Failure- Age Abcissa as Failure-Stress scale (F.S. axis - Percent Increase above R.B. levels). Actually the reliability boundary may be made to coincide with the percent failure ordinate thus representing 1.001 x Reliability Boundary.

4.5.2.3.3 Determine the median rank for each failure in the sample (Ref. 1,2,3,4) and plot these values on the Weibull paper.

The use of median ranks may be explained as follows: The first failure in a sample of, say ten units, represents an estimate of the percentage of the total population which would fail prior to the stress at which the first failure in the sample occurs. If the percentage of the population failing before the first failure in ten were known, then this percentage would be the true rank of the first failure in ten. However, the true rank is unknown, so an estimate of the true rank is used. If the estimate has a 50% probability of overestimating (or underestimating) the true rank, then the estimate is called a 50% rank, or Median Rank. (The 100 α % rank values are calculated by use of the Incomplete Beta Function Ratio, Ip, (a,b)= α).

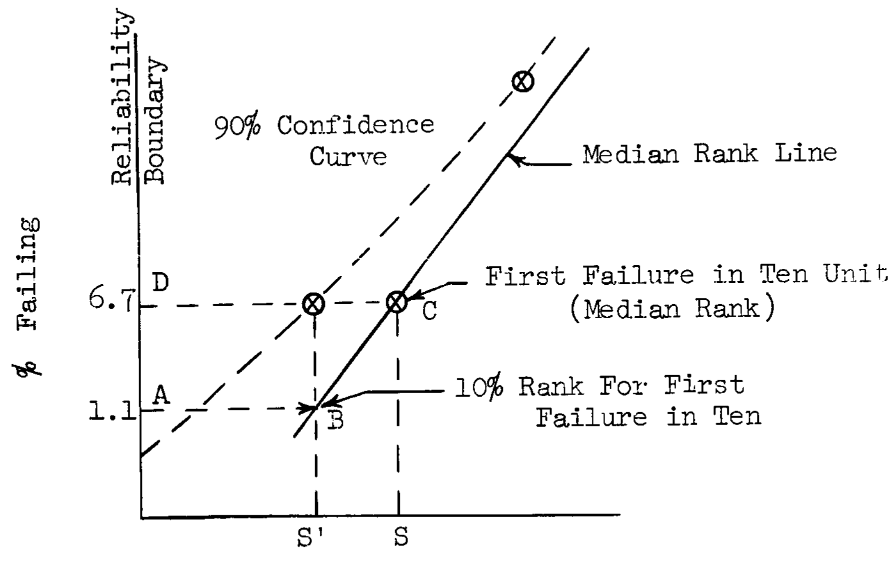
4.5.2.3.4 Draw a straight line in the direction of the array of points such that the line results in a 50-50 split of the points. This line represents an estimate of the total population from which the sample was drawn.

Since median ranks have been plotted, the danger of underestimating (or overestimating) the slope (i.e. m) by putting the line too close to the lower (or upper) points is eliminated.

4.5.2.3.4 It is entirely possible that the best fit to the median ranks will occur as other than a straight line; it could be a smooth curve openingto the left or right, or it could be a straight line with a relatively sharp bend in it (i.e. composed of a portion of each of two intersecting straight lines). Techniques are available for analyzing each of these situations in the context of the test program.

4.5.2.3.5 Determine a ten percent rank for each failure in the sample (Ref. 3,4,5). (A 10% rank value is equal to a lower 90% confidence value, where confidence represents the probability that a specified percent of the population will fail before a specified stress level). Plot the 10% rank values (i.e. 90% confidence values) for each failure in the sample as described in Figure 4.3, on the median rank line. The go up vertically to the median rank level (6.7% in this illustration)

Weibull Paper



STRESS LEVELS FIG. 4.3

4.5.2.3.6 Draw a smooth curve connecting these simularly constructed points, one for each failure, and extend the curve until it intersects the Reliability Boundary Axis.

4.5.2.3.7 If the 90% confidence curve intersects the Reliability Boundary axis at a percent failure no greater than five percent the equipment is considered to have complied with the reliability assurance requirements. Otherwise, the equipment is rejected. The reliability assurance requirements specified above may be stated as follows: An equipment must demonstrate at 90% statistical confidence no more than a five percent probability of failure below the Reliability Boundary.

4.5.3 <u>Example Problem</u>

An example of the application of this Weibull technique to a sample problem has been prepared for inclusion in the LEM Vendor Requirements, and is presented below:

<u>Example</u>

Assume that ten units of a given equipment are subjected to the Reliability Boundary conditions (0.08" d.a. constant 100 cps sinusoidal vibration and 50°C) for one mission cycle. The Reliability Boundary conditions are then increased in ten percent increments (temperature increase based upon operating range of 0°C to + 50°C) until each unit has failed. The failures are listed in chronological order along with the percent above the Reliability Boundary at which each failed.

FAILURE NUMBER	PERCENT ABOVE RELIABILITY BOUNDARY	VIBRATION & TEMPERATURE LEVELS
1	10%	100 cps, 0.088" DA, 55°C
2	20%	100 cps, 0.096" DA, 60°C
3	30%	100 cps, 0.104" DA, 65°C
4	40%	100 cps, 0.112" DA, 70°C
5	50%	100 cps, 0.120" DA, 75°C
6	60%	100 cps, 0.128" DA, 80°C
7	70%	100 cps, 0.136" DA, 85°C
8	70%	100 cps, 0.136" DA, 85°C
9	80%	100 cps, 0.144" DA, 90°C
10	90%	100 cps, 0.152" DA, 95°C

4.5.3 (continued)

From a table of median ranks (Ip(a,b) - 0.50) the following median rank values are assigned to each failure in the sample:

FAILURE NUMBER	MEDIAN RANK(%)	STRESS LEVEL ABOVE RB (%)	FAILURE NUMBER	MEDIAN RANKS(%)	STRESS LEVEL ABOVE R.B.(%)
1	6.7	10	6	54.8	60
2	16.3	20	7	64.4	70
3	25.9	30	8	74.1	70
4	35.6	40	9	83.7	80
5	45.2	50	10	93.3	90

These median ranks are plotted on Weibull probability paper. (Figure 4.4)

Since it appears that a straight line provides the best fit to the plotted median rank points, a straight line is drawn in the direction of the array such that it splits the array 50-50.

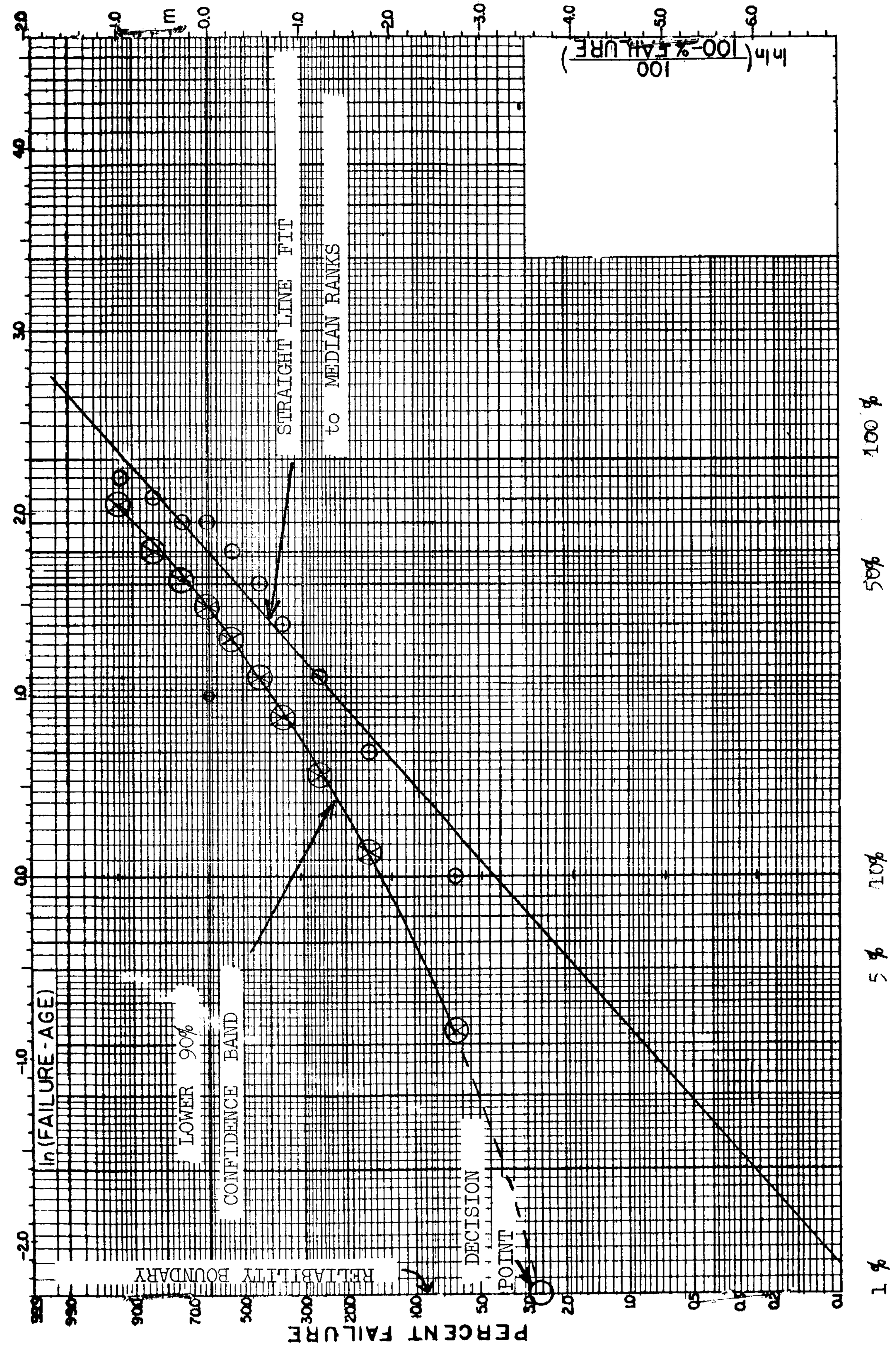
From a table of 10% ranks (Ip (a,b) = 0.10), the following values are determined for a sample of size ten:

FAILURE NUMBER	TEN PERCENT RANKS	FAILURE NUMBER	TEN PERCENT RANKS
1	1.1	6	35.4
2	5.5	7	44.8
3	11.5	8	55.0
4	18.8	9	66.3
5	26.7	10	79.4

A ten percent rank is plotted as shown on Figure 4.4 Page .

For the first failure in ten, the 10% rank is 1.1%. Draw a horizontal line from the 1.1% point on the Reliability Boundary axis (A) to the median rank line. Draw a vertical line through point B. Draw a horizontal line from the median rank percent failing for the first failure in ten to the Reliability Boundary Ordinate (CD). The intersection of line CD and the vertical through B defines the lower 90% confidence point for the first failure in a sample of ten. This point represents a 90% probability that 6.7% of the failures of this equipment type will occur at a stress level no lower than S'. The ten percent ranks for the nine remaining failures are plotted in a similar manner.

WEIBULL PROBABILITY PAPER



SCALE in % ABOVE RELIABILITY BOUNDARY

FIGURE 4.4

4.5.3 (Continued)

Connect the ten confidence points with a smooth curve, and extend the curve until it intersects the Reliability Boundary, or Percent Failing Axis. This intersection occurs at approximately 2.75 percent. Therefore, a decision is made to accept the equipment type as having passed the Reliability Assurance Requirements (no more than 5% failing below the Reliability Boundary stated at 90% confidence). The amount of subjectivity involved in extending this curve is expected to be controlled to within one percent of the true extension (Figure 4.4).

REFERENCES

1. Johnson, L.G., The Median Ranks of Sample Values In Their Population With An Application to Certain Fatigue Studies, General Motors Research Reliability Manual, 1960.

2. Everdell, R., Lecture Series on Statistical Engineering, Lectures 4-7, GAEC, August 16, 1962-October 11, 1962.

3. Simon, L. E., An Engineer's Manual of Statistical Methods, Curves for Reading Inverse Solutions of the Incomplete Beta Function, John Wiley, 1951.

4. Pearson, E. S. and Hartley, H.O. (editors), Biometrika Tables for Statisticians, Table 17, Vol. I, Cambridge University Press, 1954.

5. Burington, R.S. and May, D.C., Handbook of Probability and Statistics, Table III, Handbook Publishers, Inc. 1958.

4.6 SELECTION OF EQUIPMENT FOR RELIABILITY ASSURANCE ESTIMATE-

Reliability assurance estimates are, in general, conducted on as high a level of assembly that the compatibility of components, interaction among components, and the integrity of the assembly as a functioning whole are best assessed.

However, it is imperative that weak elements be uncovered early enough in the test program so as to avoid expensive and time consuming redesign at such a late date as that at which the higher level of assemblies are generally tested. Therefore, the level of assembly for testing may require a trade-off of some engineering confidence versus the timeliness of the tests.

The levels of assembly, and the associated equipment, which will yield the most pertinent and timely reliability data varies from one subsystem to another. The selection of equipment for reliability assurance estimates must be tailored, individually, for each subsystem so that, in conjunction with other tests,the necessary reliability confidence is acquired which will permit the subsystem to be accepted for use in the LEM.

4.7 VERIFICATION OF STRENGTH MARGINS-

In addition to the tests applicable to relability assurance, other stress-to-failure tests are employed, throughout the test program for the purpose of checking strength margins of equipment for which a complete reliability assurance test cannot be justified within the constraints of time and cost.

Two test units are aged in accordance with the "operating rectangle", and then failed under increasing stress as described previously. In this test, however, only two (2) failures are required. If both failures occur above a specified strength margin described above, further reliability testing is not required at this point. If not, further stress-to-failure testing may be conducted on this equipment.

4.8 TEST PROGRAM IMPLEMENTATION

The Grumman Test Program will be implemented through the concerted efforts of the individual Subsystem Engineers, the Systems Test Section, the Flight Test Section and the Reliability Systems Section. Quality Control will monitor qualification and acceptance test operation to assure compliance with the procedures defined in the test plans prepared by the above test functions.

The specific role of the Reliability Test Group will be to provide support in these major areas:

a- Procurement Documents
b- Subcontractor Negotiations
c- Test Criteria (Development, Qualification, Acceptance)
d- Review of Test Plans
e- Reliability Test Plans (Review and/or Preparation)
f- Analysis of Results or Evaluation of Analysis
g- System (Ground) tests
h- Flight Development Program
i- LEM Reliability Test Program Assessment
j- Training Programs.

4.8.1 Procurement Documents- Reliability assurance requirements are specified in all of the procurement documents for subcontracted equipment. These requirements specify the stress-to-failure tests as the primary tool for reliability assurance in the "Design Verification" stage of the vendor's development program.

In addition, where applicable, the test to failure is utilized as an early stage check on the strength of components before they are integrated into higher orders of assembly.

The reliability assurance requirements are not boiler plated in the procurement specifcations. Each subcontracted equipment is slated for reliability estimates at the most logical level of assembly. Factors such as interrelation of components, complexity of environmental and operating parameter simulation, location or arrangement of equipment, and timeliness of the test in relation to the development, program are factors affecting the selection of level of assemblies.

4.8.2 Vendor Negotiations-

In order to assure that the reliability assurance requirements are carried out in the contract, the reliability test group will participate in the vendor negotiations for all purchased equipment. These negotiations are segmentized into an effort analysis stage and a negotiating stage. In effort analysis, the vendor presents the program he proposes to answer the Grumman Reliability Assurance requirements, along with the manpower and hardware associated with fulfilling the requirement; this program is then negotiated into the definitive contract in a manner and approach which is satisfactory to the Grumman Reliability Group.

4.8.3 Test Criteria-

The reliability test group assists the other agencies responsible within the LEM project for the overall test program in establishing goals and criteria for all aspects of the program from development through qualification and acceptance tests.

4.8.4 Review of Test Plans-

The reliability test group will review all test plans which are submitted to Grumman or generated within Grumman. These plans will be reviewed to determine whether the test is designed to yield a maximum of reliability information. Where practical tests will be modified to yield failure mode information and add to the confidence in the strength of the equipment.

Reliability Assurance test plans will be reviewed to determine whether correct procedures (Ref. para. 4.5) will follow.

4.8.5 Reliability Test Plans-

In house Grumman tests will require the assistance of reliability personnel in the preparation of plans for equipment to be tested at Grumman facilities. The tests will range from the statistical or factorial design type for material and component selection, to stress to failure tests for measurement of material or equipment strength with some statistical confidence.

4.8.5 Analysis of Results- Test reports for all tests will be reviewed by reliability test engineers for specific reliability content. Reliability, assurance reports will be subjected to close scrutiny to assure that the test procedures were in accordance with the test plan and that the analysis and the reliability assurance statements based thereon were validly determined.

4.8.6 System Tests- The fulfillment of reliability assurance requirements and qualification test objectives at the component or section level of assembly will demonstrate the quality of the product and the integrity of the design to such an extent that hardware delivered to Grumman for integrated subsystem or system level testing should present a minimum of problems arising from component or section failures. However, as a logical extension of the subsystem development and qualification tests programs the same degree of surveillance will be maintained by the reliability systems section during the conduct of the entire system ground test program.

The monitoring activities will be pursued to assure that the subsystem and system test will be utilized to add measurably to the engineering confidence in the LEM system capability.

4.8.6.1 Engineering Development Model Tests- The specific contribution of early development boiler plate and scale model tests to reliability aspects of the program will be to provide the first empirical look at some of the environmental and operating parameters which might occur in the LEM mission. For instance, the thermal test model (TM-2) will generate first cut information on the distribution and magnitude of temperature in the LEM structure at a time when substantiation of k factors for failure rate data used in reliability analyses are most needed. Other boilerplate type models will also yield information of varying degrees of usefulness to the reliability program.

4.8.6.2 Propulsion System Tests- Cold flow tests at Grumman and hot firing tests at WSMR will provide singularly useful data for the reliability assurance program. The multiplicity of tests which will be run on boiler plate and flight weight propulsion rigs, alone will add measurably to the engineering confidence in these critical systems.

A program will be initiated whereby, with little or no additional hardware, selected hot firing tests of the ascent, descent, and reaction control subsystems at WSMR will be run to failure at critical operating conditions to support accumulated data of the vendor test programs. This program will carry through the development program on heavy weight and prototype rigs to thepropulsion system qualification test on LTA-5.

The selection of tests for firing to failure will be made on the basis of similarity of cycles during the mission duration phase and the specific conditions (mission simulation or off design) which have proven to be most significant in previous engine firing tests at the vendor's test sites.

4.8.6.3 LTA System Tests- The system test program will feed back additional environmental and dynamic measurements to help substantiate the development program analyses. In general a high degree of engineering confidence will be gained from the LTA program since subsystem compatability will be proven under conditions approximating the actual mission operating conditions. The following activities will be followed on all of the LTA Systems Ground Tests:

4.8.6.3.1 Test plans for subsystem and system tests will be reviewed,modified, or extended in order to generate, when and where practical, additional data points to support previous reliability estimates.

Code 26512 Eng-23A

4.8.6.3.2 Tests will be monitored closely by the cognizant reliability subsystem engineer to be sure that the test is run according to the plan, and more specifically where reliability considerations have injected some modification or extension.

4.8.6.3.3 All failures not intended as part of the test plan will be reviewed to determine the cause of the failure and whether the failure mode bears resemblance to any failure mode uncovered in component or section development or qualification test program, especially failure modes detected in the stress-to-failure tests.

The failed component will also be examined to discover whether the failure was the result of a defect in quality or the manifestation of a problem of system integration or interaction.

If a new or unanticipated failure mode is detected, the reliability systems engineer must of necessity re-check his failure effect analyses to determine the impact on the total system reliability. Regardless, of the outcome of these investigations, the reliability systems section shares the responsibility with the cognizant susbsystem engineer in determining the appropriate corrective action.

4.8.6.3.4 As a corollary to the above,the results of all tests must be reviewed to determine whether data supports earlier assumptions (in design analyses for instance) and if not, to re-assess the analyses based on the additonal information.

4.8.6.3.5 Based on the degree of environmental simulation experienced in each system test, the severity of the conditions, the state of completion of the component hardware (boiler plate, prototype, qualified), the correlation of actual results with the predicted, each successful test will be weighted as to its contribution to the engineering confidence in the overall LEM system.

4.8.7 Flight Test Program- The flight development program will feed back vital data to the program from the standpoint that each successful step will represent a giant step in the build up of confidence that the LEM will perform its appointed mission without mishap.

Prior to each launching several progressive acceptance tests will have been performed, each one adding considerable weight to the reliability estimate of the LEM. (Ref. The Test Plan for the LEM). In general these tests will be:

a- Acceptance and Functional Tests - Grumman Facilities
b- Integrated Tests (LEM/booster or CM/SM/LEM/5-IVB)
c- Launch Tests- Final checkout of all systems

Data from the prelaunch tests will be correlated to the results of the development and qualification tests programs in as much as the latter were used to design an effective acceptance test program.

Malfunctions experienced both in the prelaunch and operational phases of the flight development program will be investigated to fullest extent possible. The history of the failed component will be traced by way of the "Test Identification Program" back through the development program to determine whether the failure mode had appeared before, at what stress levels or under what environments it appeared, whether the failure was one resulting from poor quality or design deficiency, etc.

Failure reports will be made on any malfunctions detected during this program. The reports will be analyzed to detect possible trends with special attention being made to the detection of wear-out patterns.

4.8.8 LEM Reliability Test Program Assessment-

No attempt will be made by the Grumman reliability test group to make periodic estimates of the LEM reliability improvement on the basis of MTBF's generated during the test program.. Experience has shown that the value of such estimates is limited due to the arbitrary manner in which MTBF data are collected. In as much as the only MTBF's worthy of application to analyses are those generated during an actual mission, relative few opportunities will arise to obtain valid data early enough in the program to be effective.

Therefore, the results of the stress-to-failure tests will provide the only formal estimates of the LEM reliability program. These estimates will be attached to the specific level of assembly tested under the reliability assurance requirements. The reliabilities measured for the lower level of assembly may be projected to yield a system level reliability. However, since apportioned reliabilities will not be demonstrated, any values so derived will only serve to point up potential problem areas, or provide a basis for comparison studies.

SECTION 5

DOCUMENTATION SUBMITTALS

5.1 Grumman Reliability Documentation submittals will be in accordance with Appendix II of reference (e) as follows:

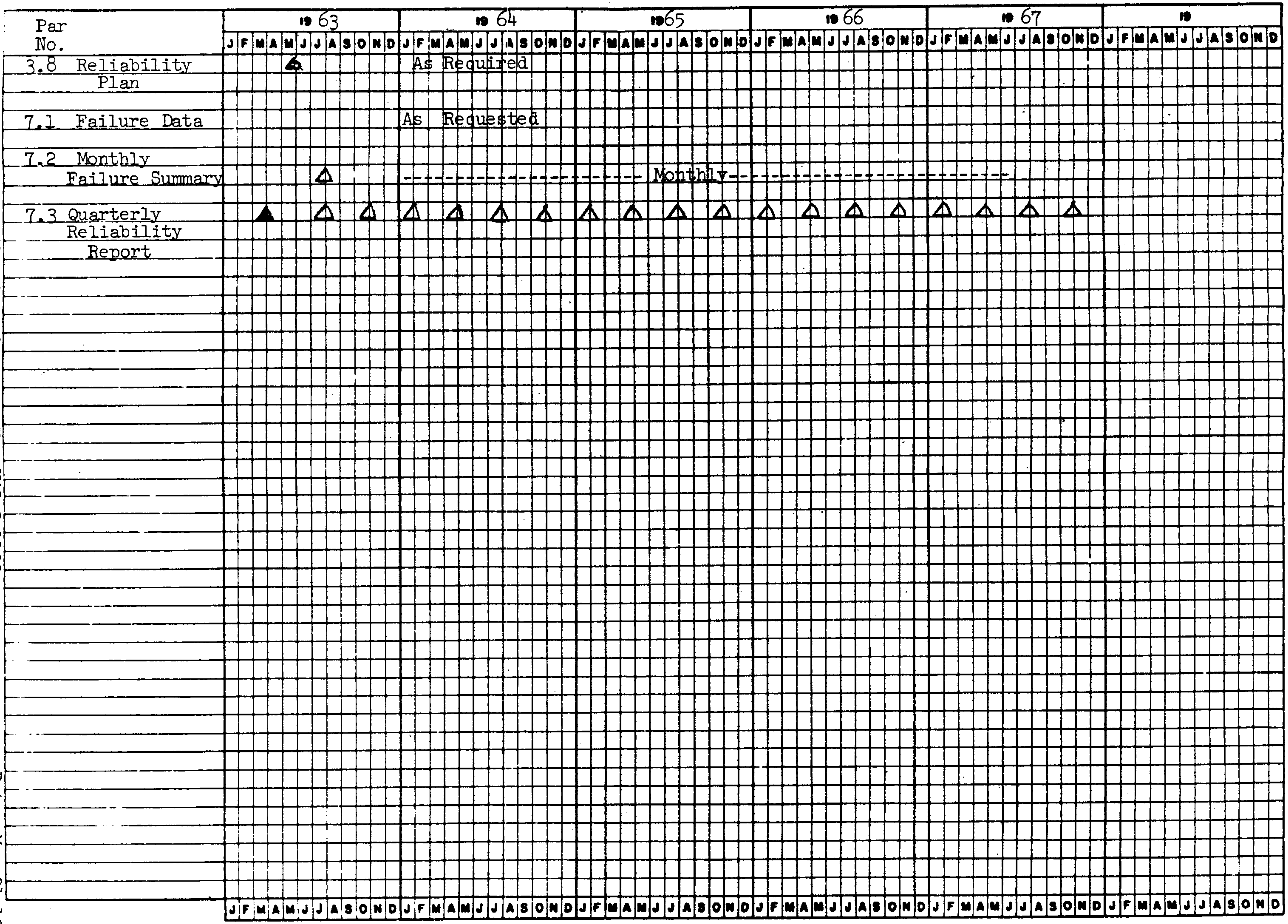
Documentation Type & Delivery Schedule

Requirement Paragraph No.	Item	Initial Delivery (Months)		Documentation Type	Approx. No. of Copies
3.8	Reliability Plan	4	Updated upon written request by MSC-ASPO. On the average, revisions will be required about once every two months until they are initially acceptable and about once every six months thereafter.	I	50 Prior to NASA approval 100 Sequent to NASA Approval
7.1	Failure Data	As requested		II	2
7.2	Monthly Failure Summary	10 days after sixth month	10 days after end of each month	II	10
7.3	Quarterly Reliability Status Report	1 month after end of first month	1 month after end of each calendar quarter.	II	20*
*	As directed by NASA	14 6	copies to NASA-MSC copies to NASA- Hdqts.		

SECTION 5

5.2 Reliability LED Submittals- The following data will be submitted to the NASA- RASPO office at Grumman as completed prior to incorporation into the next Quarterly Reliability Report.

a. Configuration Analyses
b. Circuit Analyses
c. Failure Mode and Effect Analyses
d. Reliability Estimates
e. Maintainability Analyses
f. Acceptable Parts Listing



DOCUMENTATION SUBMITTAL

DATE ____________

Appendix A

Subcontractor Reliability Control

1. Requirements

1.1 Design Specification

1.1.1 Reliability- Numerical Requirement

Example - Ref: LSP-270-5

(3.9) Reliability

(3.9.1) Mission Success and Safety.- The probability of success and probability of safety goals are equal and shall be 0.999982 for completion of the mission requirements specified herein. The goal shall include all operating and non-operating phases of engine life specified in Table IV as well as catastrophic failure such as explosion or propellant leakage causing serious damage to initial equipment.

(3.9.2) Operational Profile.- The reliability requirements of 3.9.1 shall be based on the operational time and environmental parameters specified in Tables II and IV.

1.1.2 Reliability Assurance

(4.4.2) Reliability Assurance- As an integral part of the analysis of the data from the development tests, the vendor shall estimate the reliability inherent in the design. This estimate shall be made for the highest order of assembly deliverable to Grumman. The estimate of reliability shall be based on data from tests which fulfill the following essential requirements:

1.1.2 Reliability Assurance (continued)

(4.4.2)

(a) The tests are conducted on specimens which are representative in design physical configuration and material to the proposed production equipment.

(b) The specimens are tested to failure under systematically increasing dynamic and environmental stresses. Attention is to be given to subjecting the specimens to combined dynamic loads and environments wherever the combined effects exist and may be critical. Operating time or number of cycles shall not be overlooked as possible criteria variables.

(c) Prior to the stress to failure tests the specimens shall have been subjected to one mission simulation at the critical reliability boundary conditions of 4.4.2.1.1 with the specimens operating or non-operating as applicable. The mission environments and dynamic conditions to which the equipment will be exposed during the acceptance tests, handling, transportation and storage, prelaunch, launch, translunar and lunar phases of the LEM mission.

(4.4.2.1) Reliability Assurance Requirement- as an integral part of the analysis of the data from all development tests, the vendor shall demonstrate by statistical analysis of the results of the stress-to-failure tests that the probability of occurrence of a failure at levels of severity less than the critical environmental, dynamic, or operation conditions established by the Reliability Boundary is no more than 5%. This statement shall be made with a statistical confidence of 90%.

1.1.2 Reliability Assurance (Continued)

(4.4.2.1.1) Reliability Boundary- The Reliability Boundary may be established by:

(a) From Available Empirical Data- Where reliable data is available which can be applied to the LEM mission, the Reliability Boundary shall be established as that level of environmental, dynamic, or operational severity for which the probability of occurrence of a more severe environment in the actual mission shall not exceed 1%.

(b) By Sound Engineering Judgment- When no acceptable empirical data is available, the Reliability Boundary will be set at 1.15 times the maximum mission design conditions of temperature, vacuum, and associated space environments shall be established on the basis of engineering judgment and shall contain similar margins. The Reliability Boundary should be representative of the mission profile so that the failure mode predicted in accordance with the purchase order data requirements will be uncovered.

(4.4.2.1.2) Analysis of Results- Failure data accumulated in the stress-to-failure tests shall be subjected to a graphic Weibull analysis (described in the data requirements of the purchase order).

Appendix A

1.1.3 Table II - Environmental and Load Conditions

Example:

NOTES:

1. Factors of Safety are not included in the levels specified herein and shall be applied to these values and self-generated loads of each subsystem in accordance with Table II-a. (See also 3.4.1.1 and 3.4.2).

2. All accelerations are "earth g's". Multiply by earth weight or use 32.2 ft/sec.^{2} as appropriate.

(a) Pre-Launch

Acceleration: 2.67 g vertical with 1.0 g lateral

Shock
  Packaged: Transportation, handling and storage in shipping container shall not produce critical design loads on the engine and shall not increase weight of the engine.

Unpackaged: - 3.0 g Peak 2 to 20 ms. any axes.

Vibration: The following vibration levels are specified during transportation, handling and storage. Vibration to be applied along three mutually perpendicular axes, applied to the container. (x, y & z)
(Sweep at 1/2 octave per minute.)

CPS	less than 50lb.	50 to 1000 lb.
5 to 27.5	±1.23 g	± 1.00 g
27.5 to 52	0.033 D. A.	0.027 D. A.
52 to 500	± 4.61 g	± 3.84 g

Pressures: Atmospheric pressure corresponding to sea level to 50,000 ft. (Hermetically sealed units installed in the crew compartment will be subjected to a limit pressure of 20 psi absolute during pre-flight check-out).

Temperature: -60 to +160°F

Humidity: 0 to 100 percent relative humidity including condensation.

Rain: In accordance with MIL-STD-810 Method 506.

TABLE II - Environmental and Load Conditions (continued)

(a) Pre-Launch (continued)

Salt Fog:	In accordance with MIL-STD-810 Method 509.
Sand and Dust:	In accordance with MIL-STD-810 Method 510.
Fungus:	In accordance with MIL-STD-810 Method 508.
Ozone:	Exposure with 0.05 parts/million concentration.
Hazardous Gases:	Explosion proffing requirements defined in MSFC Dwg. 10M01071.
Electromagnetic Interference:	In accordance with LSP-14-2.

(b) Launch and Boost

Acceleration:

	X	LATERAL	PITCH
cond. boost	+5.64g	+3.34g	+1.27R/sec.^{2}
cond. burn-out	-1.[illegible]g	0g	0R/sec.^{2}

Vibration: Sinusoidal vibration shall be superimposed on random vibration.

Random Vibration: Random vibration shall be 1[illegible] mins. along each of the three mutually perpendicular axes x, y, and z.

[illegible]50 cps. 0.0089 g^2/cps.
50-100 cps. Linear increase to 0.0355 g^2/cps.
100-1000 cps. Constant 0.0355 g^2/cps.
1000-2000 cps. Linear decrease to 0.0089 g^2/cps.

Sinusoidal Vibration: A sinusoidal vibration shall be superimposed sweeping logarithmically from 5 to 2000 cps. in 6 mins. for each of the three mutually perpendicular axes x, y and z.

5-10 cps. 0.154 inches D.A.
10-18 cps. $\pm$0.770 g vector
18-56 cps. 0.046 inches D.A.
56-2000 cps. $\pm$7.70 g vector

TABLE II- Environmental and Load Conditions (continued)

(b) Launch and Boost (continued)

Acoustics: sound pressure levels external to LEM (ref. 0.0002 dynes/ cm^2)

Octave Band (cps)	Apollo Level (db)	L.J. II Level (db)
9 to 18.8	142	-
18.8 to 37.5	141	-
37.5 to 75	141	143
75 to 150	138	149
150 to 300	134	155
300 to 600	130	155
600 to 1200	123	155
1200 to 2400	116	155
2400 , to 4800	110	143
4800 to 9600	104	131
overall	147	160

Pressure: Atmospheric at sea level to 1×10^{-10} mm Hg.

Temperature:
0 to +160°F uncontrolled cabin
+40 to +100°F propulsion compartment
0 to +110°F ambient S.L.
-65 to +160°F external surface of LEM

Humidity: Same as pre-launch

Hazardous gases: Same as pre-launch

Electromagnetic Interference: Same as pre-launch

Radiation: See 3.4.1.2

(c) Space Flight	X	Lateral	Pitch
Acceleration: condition	-0.450g	0.110g	0.373 rad/sec^2
Shock:			
condition (a)	-0.32g	0.093g	0.4 rad/sec^2
condition (b)	-0.84g	0.12 g	17.0 rad/sec^2

Vibration: Sinusoidal vibration shall be super-imposed on the random vibration.

Random Vibration: (s.p.s. operating) Random vibration shall be 6 mins. for each of the mutually perpendicular axes x, y and z.

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TABLE II- Environmental and Load Conditions (continued)

(c) Space Flight (continued)

Random Vibration: (s.p.s. operating)-
5 cps. 0.00415 g^2/cps.
5-100 cps Linear increase to 0.0237 g^2/cps.
100-200 cps. Constant 0.0237 g^2/cps.
200-2000 cps Linear decrease to 0.0089 g^2/ cps.

Sinusoidal Vibration: (s.p.s. operating)
A sinusoidal vibration shall be superimposed sweeping logarithmically from 5 to 2000 cps in 2 mins. for each of the three mutually perpendicular axes; x,y,and z.

5-300 cps Linear increase 0.0924g to 1.925g
300-1000 cps Constant 1.925 g
1000-2000 cps Constant 1.54 g

Pressure: 1×10^{-14} mm Hg uncontrolled vacuum

Temperature: 0 to 160°F in equip. bay +40° to +100°F in propulsion comp. & ascent engine.

Ozone: To be determined

Hazardous Gas: Explosion proof per MSFC Dwg. 10M01071

Electromagnetic Interference: Same as prelaunch

Radiation: Van Allen, Solar Flare & Space back-ground. To be defined as needed (inner belt 10 min. 1/2 hr. delay - outer belt 20 min. approximately) See 3.4.1.2

(d) Lunar Descent (Including separation, descent, hover and touchdown)

Accelerations:	X	Lateral	Pitch
descent conditon:	1.10g	0.16g	0.667 rad/sec^2

Shock: (landing) To be supplied by Grumman

Vibration: Sinsoidal vibration shall be superimposed on the random vibration.

Random Vibration: Random vibration shall be 11-1/2 mins. for each of the three mutually perpendicular axes; x, y and z.

TABLE II- Environmental and Load Conditions (continued)

(d) Lunar Descent

Random Vibration	5 cps - $0.0051g^2$/cps
	5-100 cps Linear increase to $0.0415g^2$/cps
	100-550 cps. constant $0.0415g^2$/cps
	550-2000 cps. Linear decrease to $-0.0296g^2$/cps.
Sinusoidal Vibration:	A sinusoidal vibration shall be superimposed sweeping logarithmically from 5 to 2000 cps in 4 mins. for each of the three mutually perpendicular axes; x, y and z.
	5-400 cps. Linear increase 0.123 to 5.39g
	400-2000 cps constant 5.39g
Pressure:	1×10^{-12} mm Hg uncontrolled vacuum
Temperature:	0 to +160°F in (vacuum) equipment bay
	40° to + 100°F in propulsion comp. and ascent engine.
Ozone	To be determined
Hazardous gas:	Explosive proof per MSFC Dwg. 10M01071
Electromagnetic Interference:	Per LSP- 14-2

(e) Lunar Stay

Accelerations: cond. - at rest	X 1/6g	Lateral 0g	Pitch 0 rad/sec.^{2}
Shock:	Not critical		
*** Vibration:			
Pressure:	1×10^{-12} mm Hg uncontrolled vacuum		
Temperature:	0 to +160°F in (vacuum) equip. bay 40° to +100°F in propulsion comp. and ascent engine		
Ozone:	To be determined		

Table II- Environmental and Load Conditions (continued)

(e) ***Vibration

(a) Vibration due to other sources to be supplied by Grumman.

(b) Ascent and descent engines not operating

Hazardous gas:	Explosive proof per MSFC Dwg. 10M01071
Radiation:	Solar Flare and Space background to be defined as needed. See 3.4.1.2
Electromagnetic Interference:	Per LSP - 14-2.
Sand and Dust:	This is to be specified by Grumman.

(f) Lunar Ascent

Pressure:	1 x 10^{-12} mm Hg uncontrolled vacuum
*Temperature:	0 to +160°F in vacuum equip. bay 40° to +100° F in propulsion comp. Solar radiation = 440 BTU/ft^2hr. Lunar surface = -300°F to +250°F depending on position of sun Space = -460°F
Ozone:	To be determined.
Hazardous gas:	Explosive proof per MSFC Dwg. 10Mo1071

* The aft end of the ascent rocket engine is exposed to a combination of these environments during ascent and rendezvous. The exposed area will consist of the exit area of the exhaust cone that can be seen inside the Grumman heat shield. The engine temperature caused by expected combinations of these environments shall be determined. The method by which this is accomplished shall be approved by Grumman.

Radiation:	Solar Flare and Space background to be defined as needed. See 3.4.1.2
Electromagnetic Interference:	Per LSP- 14-2
Meteoroids:	Use Whipple's Flux distribution for sporadic meteoroids as specified in Table III.

Table II- Environmental and Load Conditions (Continued)

(f) Lunar Ascent (continued)

Sand and Dust: This is to be specified by Grumman.

Acceleration:	X	Lateral	Pitch
ascent condition:	1.2g	.06g	2.0 rad/sec^2

Shock: To be supplied by Grumman.

*** Vibration: Sinusoidal vibration shall be superimposed on the random vibration

***Vibration - Vibration, self-imposed due to ascent engine firing, shall be supplied by the Vendor.

(a) Vibration due to other sources to be supplied by Grumman.

TABLE II-A

ENVIRONMENTAL AND LOAD CONDITIONS LIMIT, PROOF, AND ULTIMATE FACTORS

	TABLE II values (mission levels) Limit Factors for all loads due to Table II levels	ULTIMATE Ultimate Factors (for structural loads) that shall be applied to limit loads (c)
Accelerations	1.0	1.5
Shock	1.0	1.5
Vibration g^2/cps	1.0	$(1.3)^2$ or 1.69
Vibration g and D.A.	1.0	1.3
Pressure Vessels*	1.0	2.0 (p)
Pressure Vessels (fuel tanks)	1.0	1.5 (c)
Acoustics	1.0	1.3
Temperature	1.0	1.0
Humidity	1.0	-
Rain	1.0	-
Salt Spray	1.0	-
Sand and Dust	1.0	-
Fungus	1.0	-
Ozone	1.0	-
Hazardous gas	1.0	-
Radiation	1.0	-
Electromagnetic Interference	1.0	-
Meteoroids	1.0	-

* proof pressure on all pressure vessels is 1.33 x limit.

(c) combined loadings shall be considered.

(p) pressure only (includes cabin, etc., excludes main propulsion tanks).

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1.1.4 Table IV - Typical Engine Life Cycle

Example: -

TABLE IV

TYPICAL ENGINE LIFE CYCLE

Event	Operating time (seconds)	Non-operating time (hours)	Environmental and load conditions from Table II
Pre-launch (NOTE 1, acceptance test)	45		
Pre-launch (ready condition		180 days	a
Launch, boost		0.3	b
Space flight to LEM separation		72	c
Lunar Descent			d
Lunar Stay		24	e
Lunar Ascent	340		f
Coast		28	f (excluding vibration)
Midcourse Correction	5		f
Coast		2	f (excluding vibration)
Rendezvous & Docking	50		f

*Ready Condition - period between final acceptance test until launch (packaged or unpackaged; outside the vehicle or installed in the vehicle.)

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1.1.4 Table IV - Typical Engine Life Cycle (Continued)

NOTE 1: Acceptance testing shall be performed at the Vendor, WSMR and AMR facilities. The acceptance testing shall be limited to 45 seconds for each facility. Between acceptance testing, the rocket engine shall be subjected to transportation transients enroute to the respective facilities.

APPENDIX A

1.2 Vendor Requirement Document

1.2.1 Task Descriptions - Section C

(6) Reliability Program.

(6.1) Reliability Program Plan.- The vendor shall prepare a reliability program plan that describes in detail the manner in which he shall comply with the requirements of the following paragraphs.

(6.2) Reliability Reports.- The vendor shall prepare reliability reports at regularly scheduled intervals as specified in the documentation section of this document. The report shall contain information on the status of the reliability effort and shall include the following items:

(6.2.1) Analysis Effort.- The analysis effort shall include but not be limited to the following specific tasks:

(6.2.1.1) Reliability Apportionment and Estimates.

(6.2.1.1.1) Reliability Apportionment. - As a method of approach towards achieving the overall reliability requirement, the equipment reliability shall be apportioned among the various components on the basis of their relative complexity and relative importance to the successful operation of the equipment as indicated by the failure effect analysis. This initial apportionment shall be refined as the design progresses to reflect mission times, redundancy applications, multi-model concepts and other factors. The apportioned requirements shall be maintained up-to-date throughout the program in order to provide definitive design and test objectives for the hardware at all levels of assembly. All deviations from the initial apportionment shall be explained and noted in the Reliability Status Report.

(6.2.1.1.2) Reliability Estimates.- All phases of the design effort shall be monitored and up-to-date estimates of the reliability of all items of equipment and components shall be maintained. Reliability estimates shall be prepared in accordance with the procedures established in MIL-STD-756 (WEPS). Reliability estimates for electronic equipment shall be based on the failure rates listed in MIL-HDBK-217, (or updated equivalent) except that other failure rates based on carefully selected parts may be used, subject to prior Grumman approval. Consideration for approval will be based on sufficient supporting data, such as justification of failure rates, environmental test results, availability, etc. All failure rates derived from sources other than MIL-HDBK-217 shall be listed in the same units and shall refer to the same performance and environmental conditions as the failure rates appearing in MIL-HDBK-217. All failure rates, regardless of their source, shall apply to parts which will be used in the delivered product. Reliability estimates for non-electrical equipment or components shall be based on failure rates subject to Grumman approval. The periodic status reports shall compare the reliability estimates with the apportioned reliability requirements, and point out anticipated or potential trouble areas. Estimates shall be presented in such a manner that the estimate for the overall equipment, or any of its components, subassemblies, or piece-parts may be readily identified. Estimates shall not be performed on a functional basis unless specifically requested by Grumman.

(6.2.1.1.3) Reliability Data. - A reliability data list shall be prepared and shall contain as a minimum all data indicated on Table III.

It is not the intent of Grumman to dictate changes to the normal internal procedures of Vendors, however, the scope of the overall program and the number of different Vendors involved makes the use of some standardized forms essential for efficient control by Grumman. The upper section of Table III is the required configuration. The lower section configuration is at the option of the Vendor provided all information is included. The format shall be 11 x 17 inches in size. Additional data may be included at the option of the Vendor.

Note: Since the indicated column headings and codes may not be appropriate for all equipment, they may be changed as necessary at the option of the Vendor so long as the intent of the report is not altered. The following is an explanation of data required in each column of the list:

(1) Numerical designation of an item of the particular list.

(6.2.1.1.3) Continued

(2) Reference designation. Schematic designation of the item - R-101, C-121,etc.

(3) Description. All data necessary to describe the part or component such as title, value (ohms, capacitance, flow rate, pressure, etc.) Any special data such as quad configuration or reference to other documents may be made in this column.

(4) Component or part number may be Vendor or military number.

(5) Procurement Specification. The applicable military or Vendor specification must be shown in this column.

(6) Insert the name of the manufacturer and the manufacturers production lot number.

(7) Show total quantity of item used in this particular circuit or subassembly as applicable. (Diodes, valves, soldered or welded connections, etc.)

(8) Show duty cycle if applicable. The failure rate for many items such as relays, valves, and solenoids whose normal function is cyclic in nature, may be affected by the frequency of operation rather than time. Cycles may then be converted to failure rates based on total number of expected cycles.

(9) Application temperature is the maximum estimated, calculated or measured temperature in degrees centigrade. This should be updated as design and development progresses.

(10) Rates stress (volts, watts, current, pressure, pounds, etc.) is the maximum rating of the part <u>at the application</u> temperature. Show stress which is most critical to part failure.

(11) Application stress is the actual maximum applied stress in the particular circuit at the application temperature.

(12) Stress ratio is based on data in column 10 and 11.

(6.2.1.1.3) Continued

(13) Failure rate shall be indicated in failures/ 10^6 hours. Failure rate shall be preceded by a code letter keyed to failure rate source shown in the lower left hand block of the sheet. Code A and B shall be used for sources indicated. Other codes to be added by Vendor as applicable. Connections shall be included in addition to parts and components.

(14) Failure effects indicated are intended to aid in performing the Failure Effect Analysis. The code at each column heading is:

O - Open Type Failures

S - Short or Closed Type Failures

D - Degraded or Drift Type Failures

Failures shall be classified as follows and the applicable classification number inserted for each item under the failure mode indicated:

Class A - Equipment or circuit inoperative or degraded to the extent that it will no longer perform its intended function.

Class B - Equipment or circuit slightly degraded (the circuit will function but possibly not within required tolerance limits).

Class C - Nuisance type failure. No apparent degradation in performance.

(6.2.1.1.3.1) Parts Application and Standardization

All available pertinent data and information on component parts, including effects of environmental and electrical stressing, shall be utilized wherever practicable. Reference shall be made to the Inter-service Data Exchange Program files and other reports as obtainable for guidance in evaluating parts considered for use in the LEM.

Military parts included in specifications MIL-STD-242 and MIL-E-5400 will represent a minimum in quality.

All parts used in any subcontracted equipment for LEM shall be subject to the advance approval of Grumman. Such approval would be based upon the best available information, drawing upon the above-referenced sources and other relevant material.

In addition to the use of approved component parts, the subcontractor shall be obliged to de-rate the parts and apply them in circuits and functions meeting Grumman's advance approval. Thus, part application as well as part selection shall be subject to Grumman approval.

The use of "high-reliability" parts shall be considered. Use of non-standard parts shall not be approved by Grumman unless: (1) standard parts adequate for the specific application do not exist, and (2) evidence satisfactory to Grumman is produced to substantiate the adequacy of the non-standard part in both performance and reliability for the specific application.

(6.2.1.1.4) Reliability Assurance

(6.2.1.1.4.1) Reliability Assurance Plan - The vendor shall prepare a detailed plan delineating the method by which the required Reliability Assurance is to be confirmed. The plan shall list and describe the portions of the development and qualification tests applicable to Reliability Assurance, the manner in which they are integrated with other test requirements and the method by which the applicable test data is combined for Reliability Assurance Analysis.

The test plan shall include but not be limited to:

a) Purpose of test;
b) Description of test specimens;

(6.2.1.1.4.1) (Continued)

c) The test conditions and operating parameters selected for the Reliability Boundary (RB) when applicable, the basis for this selection, and the method of application;

d) The applicable mission time for the test;

e) The critical stresses and operating parameters for stress testing to failure and the reason for selection;

f) The maximum practical stress level and the increments chosen for the stress test to failure;

g) The predicted failure mode;

h) The analysis techniques to be employed to show compliance with the reliability assurance requirements;

i) The environmental stress level for establishing a curtailed test criteria.

(6.2.1.1.4.2) <u>Reliability Assurance Analysis</u>

(6.2.1.1.4.2.1) <u>Reliability Assurance Analysis</u> - The vendor shall prepare an analysis of the data resulting from the development test program to show compliance with the Reliability Assurance requirement as specified in the Reliability Assurance paragraph of Section 4 of the Design Control Specification.

(6.2.1.2) <u>Configuration and Circuit Analyses</u>

(6.2.1.2.1) <u>Configuration Analyses (Trade-off Studies)</u> - Configuration Analyses shall be prepared to assist the design engineers in making optimum decisions before a design is frozen. A configuration analysis shall compare alternate configurations, logical designs, functional arrangements, or any other schemes affecting the reliability of the equipment in such a manner as to assist the designer in selecting the optimum design. A configuration analysis completed after a design decision is made serves no purpose. A systematic effort shall be made to consider all possible schemes and arrangements before a decision is made. For each configuration, the significant parameters involved in the particular circumstances shall be identified. These parameters usually

(6.2.1.2.1) (Continued) involve considerations such as weight, cost, performance, life, maintainability, reliability, schedules, fail-safe features, etc. The various configurations under consideration usually consist of different arrangements of components or functions which all yield the same result in the main operating mode, but which may involve different degrees of redundancy and different degraded modes of operation. The significant effect of each parameter shall be evaluated quantitatively by suitable figures of merit. Normally, figures of merit are numbers which are not exact measures of parameters, but rather relative values indicating the importance of a parameter within the scope of a particular investigation for the purpose of establishing the optimum trade-offs and thus arriving at the best configuration.

(6.2.1.2.2) <u>Circuit Analysis</u> - Where applicable, an analysis shall be conducted during the design phase to assure optimum application of component parts. The analysis shall at least indicate the following data for each part used in each circuit or subassembly of the equipment: (reference paragraph 7.1.6.1)

(a) Part Performance ratings as the application environment.

(b) Loadings.

(c) Environmental conditions expected.

(d) Derating factors at the given environmental conditions.

(e) Expected failure rates at the given environmental conditions and derating factors.

(f) Symptoms and consequences of the mode of failure on the circuit and the mission capability of the system.

(g) Compensating provisions inherent in the design or alternate operating modes.

(h) Probability of occurrence of each circuit mode of failure based on the summation of the contributing component part failure rates.

(6.2.1.2.2) (Continued) The analysis shall ascertain that all component parts and modules used in more than one application are allotted a location code (part reference designator) on the applicable drawing or schematic diagram. All such drawing and diagrams shall be reviewed and signed by the appropriate circuit analyst prior to their initial release, and prior to subsequent issues following design revisions. Every effort should be made to design interchangeable modules or building blocks for various pieces of equipment to facilitate maintainability. Where electrical circuits, mechanical parts or assemblies are developed as interchangeable building blocks for equipment the analysis shall be conducted at the environments and stresses of the block in its most critical use. The data may then be applied for all building blocks in the design for the purpose of reliability estimation.

(6.2.1.3) Design Reviews - The vendor shall establish and conduct a formal program of planned, scheduled and documented design reviews at the conceptual design stage, the development stage and the design freeze stage at the component, subsystem, and system level. The reviews shall be conducted at all major milestones in the program as agreed upon by Grumman. In addition to the data requirements of the preceding paragraphs, the design review shall include but not be limited to the following items.

(6.2.1.3.1) Failure Effect and Failure Mode Prediction Analysis - The vendor shall prepare an analysis, to be submitted to Grumman prior to the design review, containing the complete details of the failure effect and failure mode analysis. The report shall also include the results of any tests which may have been performed to verify, in doubtful cases, the consequences of the assumed failure. Report updating shall consider all test failures and effect on performance.

(6.2.1.3.1.1) Failure Effect Analysis - An analysis of all conceivable failures and their effects on the mission capability of the system shall be conducted during the design phase to uncover critical reliability areas and direct appropriate engineering attention to them. In the early phases of design, the analysis shall consider the consequences of failures at higher levels of assembly. In the later design phases, the analysis shall become progressively more detailed and ultimately shall be conducted at the circuit level for electronic equipment and the piece part level (i.e. - valve, gyro, bellcrank, etc.) for non-electronic

(6.2.1.3.1.1) (Continued)

equipment. A complete failure-effect analysis shall be performed on each design and change to that design. A review of all failures during all tests shall be conducted monthly (if failures have occurred) and an evaluation of the effects of these failures, as compared to previously assumed effects, on equipment performance shall be made. The failure-effect analysis shall be revised if actual failure effects do not confirm assumed effects. The failure-effect analysis shall use the format shown as Table II and shall include the following:

(a) Block Diagram - Functional block and sequencing diagrams shall be used to define the operation of the subsystem and functional group of circuits or components. The design output requirements for each functional block shall be indicated.

(b) Item Number - This is the number assigned to each failure of each block in the block diagram for numerical identification.

(c) Assumed Failures - It shall be assumed that each functional block shall fail in turn. A systematic procedure shall be followed, where for each block, each output signal shall be assumed to fail in its most critical position or most adverse condition. Any condition where the output does not meet the design output requirements shall be considered a failure. The systematic procedure shall assure that all conceivable failure modes, at the circuit level and higher, considering all anticipated environmental and operating stresses, shall be considered.

(d) Possible Cause - This is a brief description of the cause of each failure. Examples are: shorted components, plugged or leaky components, open circuited components, or structural failure. (Identify components or parts).

(e) Effects and Consequences - Effects and consequences of each failure on the next higher level of assembly and on the mission capability of the system.

(f) Method Detection - The method or means by which the failure would first become apparent.

(6.2.1.3.1.1)
(Continued)

(g) Compensating Provisions - Compensating provisions inherent in the design or alternate operating modes. This section shall include any corrective action, either automatic or required by an operator of the equipment, the results of that action, and a indication of the resulting degree of equipment degradation.

(h) Remarks - Any statement which would augment or clarify information of the preceding columns may be provided.

(i) Probability of Failure - A numerical value denoting the likelihood that the assumed failure could be experienced. Safety margins between strengths and stresses and derating factors at pertinent temperatures shall also be indicated, as appropriate. These factors shall be based on circuit and stress analyses which include determining applied environmental, mechanical, cynamic, and electrical loads, strength of materials, and load distribution.

(j) Failure Classification - Failure classifications separates the assumed failures into categories for the purpose of providing a comparative key to the gravity of the failure. Failures shall be classified as follows:

CLASS I - Equipment or component inoperative or degraded to the point where it can no longer perform its intended function.

CLASS II - Same as Class I except that failure can be detected and corrective action taken by the crew while in flight. Corrective action may be by adjustment of equipment where such adjustments are provided, replacement of failed item where spares are provided, or by complete bypass of the failed item function by crew using other modes of operation. Failures falling in this category must be fully explained.

CLASS III - Equipment or component slightly degraded will function and perform its intended purpose but possibly not within specified limits. These failures are not catastrophic in nature.

CLASS IV - Equipment or component not noticeably affected; nuisance type failures.

(6.2.1.3.1.1) (Continued) Combined consideration of the probability of occurrence with the gravity of the assumed failure will help establish engineering priority criteria for evaluating the failures in subsequent test activities, and for consideration of equipment redesign in critical areas.

(6.2.1.3.1.2) Failure Mode Prediction Analysis - An analysis indicating the anticipated modes of failure that would occur during the required stress-to-failure reliability assurance tests shall be conducted during the design phase in conjunction with the failure effect analysis. Each mode of failure shall be related to the environment(s) at which failure is anticipated. Where practical, the prediction analysis shall state the margin above the reliability boundary for the failure mode or modes predicted. The analysis need not consider environments above the stress-to-failure test levels.

(6.2.1.3.2) Maintainability Analysis - An analysis shall be conducted to determine which components will and which will not require maintenance during the life of the equipment, and every effort shall be made to design as many components as possible such that no maintenance will be required. Maintenance diagrams shall depict the physical location of the various parts, sub-assemblies, and units on the equipment, as well as show their schematic relationship to each other. This will allow maintenance personnel to readily associate the schematic diagram with the hardware. The diagrams shall be designed for ease of comprehension and use by technicians with a minimum of training and experience. The drawing format and size shall be suited for the task under anticipated environmental maintenance conditions. In addition, the diagram shall be designed to lead the maintenance technician through the necessary steps to test his equipment, to detect troubles, to isolate malfunctioning components, and to perform the repair action. Primary and secondary test points shall be uniquely marked. Waveforms, voltages, pressures, and other data expected at these points should be illustrated. The maintenance diagram shall tell the maintenance man where he should take measurements and what he should observe at the selected points. Equipment which requires periodic inspection, adjustments and other maintenance must be placed in the most accessible locations along with equipment having high failure rates. Whenever maintenance is necessary during the life of the

(6.2.1.3.2) (Continued) equipment, the procedure for trouble detection, trouble isolation and repair shall be developed concurrently with the design, and the basic concepts shall be presented in the maintainability analysis. The analysis shall distinguish between maintenance during storage, test, on launch pad, and that which can be accomplished by the crew during the mission. Whenever feasible, trouble detection and isolation shall be automated compatible with economic considerations. A schedule for replacement of limited life items and Vendor recommendations for spares during the mission shall be included in the maintainability analysis. The product shall be designed for ease and safety of maintenance. Human Engineering and safety precautions shall be duly considered, and maintenance procedures which tend to cause people to make costly errors shall be avoided. Consideration shall be given to available skill levels of service personnel, to the configuration of the equipment as it appears to maintenance personnel in the field, and to the availability of spare parts, special tools, and facilities under operation conditions.

(6.2.1.4) <u>Failure Reporting and Analysis</u>

(6.2.1.4.1) <u>Failure Reports</u> - Failure reports shall be submitted for <u>all</u> failures occurring during qualification, acceptance, and developmental tests conducted by the Vendor. The reports shall be submitted in accordance with Table I.

<u>Reporting Forms</u> - Failure reports shall be made on forms to be supplied by Grumman or on an equivalent Vendor form approved by Grumman. As a minimum, the forms shall provide the following information, as applicable:

(1) Report Number

(2) Reporting Activity (Name of Vendor or Supplier)

(3) System Type, Model Number

(4) System Serial Number

(5) Equipment Type, Model Designation; Model Number

(6) Equipment Serial Number

(6.2.1.4.1)
(Continued)

(7) Component or Major Assembly

(a) Name
(b) Part Number
(c) Serial Number
(d) Manufacturer

(8) Subassembly or Module

(a) Name
(b) Part Number
(c) Serial Number
(d) Manufacturer
(e) Part Reference Designator

(9) Failed Part/Item

(a) Name
(b) Part Number
(c) Serial Number
(d) Manufacturer
(e) Reference Designator

(10) Date of Failure

(11) Time on Failed Part/Item

(a) Indicate time in hours and tenths
(b) Indicate number of cycles or actuations if applicable

(12) Name of test or other operation during which trouble was discovered

(13) Description of trouble - include physical and functional condition of failed item or assembly.

(14) Failure Cause

(15) Failure Classification

(16) Disposition of Failed Subassembly/Module

(17) Repair Action on Failed Subassembly/Module

(a) Brief description of repair action. Indicate whether repair involves adjustment only, or whether replacement of parts is required.

(b) Condition of failed parts (repairable of scrap).

(6.2.1.4.1) (Continued)

(c) Manufacturer's name, part number and serial number for each part replaced.

(d) Disposition of repaired item or assembly.

(e) Repair facility (where located).

(f) Repair time in hours and tenths.

(g) Man-hours to repair, hours and tenths.

(6.2.1.4.2) <u>Analysis of Failures</u> - <u>All</u> failures reported shall be analyzed to determine the cause, failure classification, and corrective action required. Consideration shall be given to all applicable methods of failure diagnosis, including analysis studies, tests, x-ray, dissection, chemical analysis, etc.

The analysis results shall include, but shall not necessarily be limited to the following:

(a) Failure Report Number

(b) Failure Cause

(c) Effect of failure on major component, equipment, and subsystem, including any secondary failures caused by the initial, or primary failure. Revise as required failure-effect analysis Table II.

(d) Corrective action taken or contemplated, and effective date.

(e) Corrective action verification test plan.

Appendix A

1.2.2 SPECIAL PROVISIONS - SECTION D LVR-XXX-X

(3.) As an integral part of the design, development, manufacturing and test program the Vendor shall plan and implement a reliability program to assure that a high level of reliability is achieved.

(3.2) Attainment of the maximum mission reliability and crew safety shall be the most important single consideration in the design, construction, handling and operation of the Lunar Excursion Module equipment.

(3.3) Personnel performing reliability program functions shall have sufficient, well-defined responsibility and the organizational freedom to recognize and correct problems and to initiate, recommend, and/or provide solutions.

(3.4) General. - These requirements constitute the minimum program necessary to assure the attainment of the quantitative reliability and operating life specified in the equipment detail specifications and the minimum reliability data to be furnished to Grumman.

(3.5) The technical term "reliability" as used in this specification is the probability that an item perform a required function under specified conditions for a specified period of time.

(3.6) The quantity of equipments to be produced for a program of this nature does not permit gradual reliability improvement throughout a relatively long production and operational life. Reliability must be designed initially into all equipments and maintained and controlled throughout all phases. Failures must be avoided in order to achieve crew safety and mission success. Failures cause serious schedule delays which in turn reduce the probability of success as launch windows are limited to relatively short periods when the relationship between the earth and the spacecraft destination is optimum.

(3.7) Vendors shall exercise effective reliability control over all in-plant and supplier products by implementing the following program:

(a) Vendors shall apportion their reliability requirements to all components in their equipment.

(b) Vendors shall determine all pertinent operating characteristics and strength margins of all materials, components and parts used in their equipments, under the anticipated operational stresses and environments. The terms "strength" and "stress" shall be interpreted in the broadest sense to include, respectively, all factors either <u>resisting</u> or tending to <u>produce</u> equipment failure or malfunction. "Strength" is always measured in a test-to-failure.

(c) Vendors shall provide assurance on a current basis that:

(1) Adequate safety margins or deratings exist in all parts, components and materials such that each part and component will meet or exceed its apportioned reliability requirements under anticipated operational loads and environments.

(2) The design is an optimum for its intended use.

(3) The reliability of the final product meets or exceeds the specified requirements.

(d) Vendors shall plan and conduct all test programs so that whenever possible the test results can be used:

(1) To validate assumptions made in the analyses and predictions of (c) above, in particular to demonstrate the basic strength of components at specified confidence levels.

(2) To estimate the achievement of part, component, or equipment reliability goals and margins of safety.

(3) To verify the results of failure effect analyses.

(e) Vendors shall establish adequate procedures to assure that the inherent reliability and safety margins attained in the design will be maintanined during fabrication and subsequent operations.

(f) Vendors shall establish economical reporting procedures which will enable Grumman to monitor conveniently all phases of their activities connected with the program specified in the purchase order.

(3.8) Reliability Procedures and Documentation.- The procedure, analyses and associated documentation which the vendor shall utilize to implement his reliability program are specified in Section E, "Documentation".

Appendix A

1.2.3 DOCUMENTATION - SECTION E LVR-XXX-X

1.2.3.1 Applicable Documents Paragraph 2

(2) APPLICABLE DOCUMENTS. - The following documents, of the issue in effect as of 14 January 1963, form a part of this section to the extent specified herein:

Document Number	Title
	NASA-PERT Handbook
NPC 200-2	Quality Assurance Provisions for Space System Contractors, dated April 1962
MIL-S-6644A	Specification, Equipment, Contractor Prepared, Instructions for the Preparation of
MIL-STD-15	Electrical and Electronic Symbols
MIL-STD-16B	Electrical and Electronic Reference Designations
MIL-STD-806B	Graphical Symbols for Logic Diagrams
MIL-STD-12	Abbreviations for use on Drawings and in Technical-Type Publications
QCP 2.11	Grumman Quality Control Procedure
ME 224	Grumman Tool Reporting Form
EDP 178F	Grumman Spare Parts Snap Card
MIL-STD-756	Reliability of Weapons Systems, Procedure for Predictions and Reporting Predictions of (10 October 1962)
MIL-HDBK-217	Reliability Stress and Failure Rate Data for Electronic Equipment (8 August 1962)
LSP-270-5	Engine, Rocket, Liquid Ascent, Design Control Specification for

1.2.3.2 Reliability Program - Paragraph 3.2

(3.8) Reliability Plan. - The Vendor shall prepare a reliability plan that describes in detail the manner in which he shall comply with the requirements of paragraph 6 Section C.

1.2.3.3 Reliability Reports and Data

(7) Reliability Reports and Data - Documentation is re-required to be furnished by the vendor to Grumman in order to provide a permanent record which justifies the design and fabrication of the equipment under development from the reliability view-point. Reports shall be submitted in accordance with the requirements contained herein and Table I.

(7.1) Reliability Program Plan - See paragraph 3.8.

(7.2) Reliability Assurance Plan - The vendor shall submit a Reliability Assurance Plan as required by paragraph 6.2.1.1.4.1 in accordance with Table I.

(7.3) Reliability Status Reports - The report of paragraph 3.8 Section C shall be submitted to Grumman for review and shall contain the information relating to all aspects of reliability evaluation. After initial submittal of the first reliability report, ninety days after contract award or issuance of purchase order, the reports are due monthly as a section of the monthly engineering report or as separate reports at the discretion of the vendor.

(7.3.1) Reliability Apportionment - Included in each monthly reliability report shall be the current status of the reliability apportionment.

(7.3.2) Reliability Estimates - The monthly reliability status report shall contain the comparison of the current reliability estimates with the apportioned goals.

(7.3.3) Reliability Data List - The reliability data list of Paragraph 6.2.1.1.3 Section C shall be submitted and/or updated in the monthly reliability status report.

(7.3.4) Reliability Assurance Analysis - The vendor shall submit the analysis as required in paragraph 6.2.1.1.4.2.1 thirty days prior to start of qualification test and as a condition for final acceptance of the Qualification test plan.

(7.3.4.1) Reliability Assurance Analysis Technique - The analysis technique to be used for Reliability Assurance justification is shown in Appendix I

(7.3.5) Configuration and Circuit Analysis - The vendor shall submit the analyses of paragraph 6.2.1.2 of Section C to the contractor ten days prior to design reviews or with the monthly Reliability Status Report, whichever is earlier.

(7.3.6) Failure Effects Analysis - The vendor shall submit the analysis of paragraph 6.2.1.3.1.1 Section C ten days prior to design reviews or with the monthly Reliability Status Report, whichever is earlier.

(7.3.7) Failure Mode Prediction Analysis - The vendor shall submit the analysis of paragraph 6.2.1.3.1.2 Section C ten days prior to design reviews or with the monthly Reliability Status Report, whichever is earlier.

(7.3.8) Maintainability Analysis - The vendor shall submit the analysis of paragraph 6.2.1.3.2 Section C one month after contract award or issuance of purchase order and update on a monthly basis. This analysis may be included in the regularly scheduled monthly Reliability Status Reports.

(7.3.9) Failure Reporting and Analysis - The vendor shall submit failure reports and analyses as specified in paragraph 6.2.1.4 Section C in accordance with the schedule shown in Table I.

TABLE 1 - DOCUMENTATION TYPE AND DELIVERY SCHEDULE

Para. No.	Item	Initial Delivery	Subsequent Issues	Doc. Type	Copies & 1 Repro.
7.	Reliability Reports and Data				
7.1	Reliability Program Plan	See Para. 3.8			
7.2	Reliability Assurance Plan	90 days	Monthly - as required	I	
7.3	Reliability Status Report	90 days	Monthly May be included in Engineering Report. Submit with monthly Reliability Status Report	II	
7.3.1	Reliability Apportionment	90 days	Monthly	II	
7.3.2	Reliability Estimates	90 days	Monthly	II	
7.3.3	Reliability Data List	90 days	Monthly	II	
7.3.4	Reliability Assurance Analysis	30 days prior to start of Qual. Test.	As Required	I	
7.3.5	Configuration & Circuit Analysis	10 days prior to Design Review	As Released	II	
7.3.6	Failure Effects Analysis	10 days prior to Design Review	As Released - Final report 30 days after design freeze	II	
7.3.7	Failure Mode Prediction Analysis	10 days prior to Design Review	As Released - Final report 30 days after design freeze	II	
7.3.8	Maintainability Analysis	1	Monthly - Included in Reli. Status Report	II	
7.3.9	Failure Reports and Analysis				
7.3.10.1	Failure Reports	1 week after first test in which failure occurs	Weekly	II	
7.3.10.2	Failure Analysis	Complete within two wks. of data of failure and submit w/next current Rel. Status report.- Analysis of failures occurring during qualification and acceptance tests should be conducted immediately and reports submitted within 4 days.		II	

TABLE I FAILURE EFFECT ANALYSIS

Page 1 of

EQUIPMENT: ____________

PREPARED BY: ____________

APPROVAL: ____________

ISSUE DATE: ____________

BLOCK DIAGRAM

ITEM NO	ASSUMED FAILURE	POSSIBLE CAUSE	EFFECTS AND CONSEQUENCES	METHOD OF DETECTION	INHERENT COMPENSATING PROVISIONS	REMARKS	PROB. OF FAILURE	FAILURE CLASS

[redacted]

EQUIPMENT ____________

REFERENCE SCHEMATIC ____________

LEM System & Subsystem Reliability Data List

PART NO. ____________

DATE ____________

1	2	3	4	5	6	7	8	9	10	11	12	13	14		
ITEM NO.	REFERENCE DESIGNATION	DESCRIPTION	COMPONENT PART NUMBER	PROCUREMENT SPECIFICATION	MANUFACTURER	QTY. PER UNIT	DUTY CYCLE	APPL. TEMP. °C	RATED STRESS	APPL. STRESS	STRESS RATIO	FAILURE RATE	FAILURE EFFECT		
													O	S	D

FAILURE RATE SOURCES

A) MIL-HDBK-217

B) ESTIMATED

SIGNATURE AND DATE

PARTS & COMPONENTS

RELIABILITY DATA

REV

Sheet of

[redacted]

APPENDIX A

(APPENDIX I)

(7.2.5.1) Reliability Assurance Analysis Technique. - The analysis technique described herein are based upon the assumption that the three parameter Weibull distribution is the underlying distribution of equipment failures. The choice of the Weibull distribution was made on the basis of the following:

(7.2.5.1.1) Flexibility. - The Weibull distribution contains a shape parameter which makes the Weibull a family of distributions. Many of these distributions have been shown to be of value in describing equipment failure rate patterns (e.g., constant, wear out, wear-in). The Weibull is also capable of indicating changes in failure rate patterns of an equipment.

(7.2.5.1.2) Economy. - A relatively small number of failures of an equipment type is necessary for analysis.

(7.2.5.1.3) Simplicity. - Graphical techniques make the analysis easy to handle.

(7.2.5.1.4) Theoretical. - The form of the Weibull cumulative distribution function coincides with the form of the cumulative distribution function of a general failure model (Ref. 1).

(7.2.5.2) Procedures. -

(7.2.5.2.1) A specific quantity of specimens is operated at the reliability boundary conditions for a period of time which is equivalent to the actual mission and then subjected to increasing stress levels until each specimen has failed. Before this test an upper bound to the stresses shall be established which represents the maximum practical stress level (Figure 2). This level shall be determined by giving consideration to controlling factors such as test equipment limitations, gross changes in equipment failure mode, material property changes, etc.

(7.2.5.2.2) Each failure is noted and assigned a number indicating its position in the failure sequence (e.g., 1 = first failure occurring in sample, 2 = second failure occurring in sample, etc.)

(7.2.5.2.3) Since the first specimen failure in a sample of specimens is an estimate of the percent of the population of equipments which would fail if the total population was tested, a rank must be assigned to each failure. The Median Rank, or rank whose probability of over-estimating (or underestimating) the percent of the total population that would fail at a given stress level is 0.5, is assigned to each failure. The Median Rank for each failure in a sample of ten is determined from the following table:

Failure Number	Median Rank (%)
1	6.7
2	16.3
3	25.9
4	35.6
5	45.2
6	54.8
7	64.4
8	74.1
9	83.7
10	93.3

Ref. Source: (2)

(7.2.5.2.4) The Median Ranks are plotted on Weibull probability paper. (% failed vs. % increase above reliability boundary levels.)

(7.2.5.2.5) A straight line drawn in the direction of the array is made such that the array is split 50-50. This line is a best estimate of the failure distribution of the equipment type under test.

(7.2.5.2.6) An upper 90% confidence point is plotted for each failure as follows:

(a) From the following table of 10% ranks (reference 3), for a sample of size ten determine the 10% rank for the first failure.

Failure Number	10% Ranks (%)
1	1.1
2	5.5
3	11.5
4	18.8
5	26.7
6	35.4
7	44.8
8	55.0
9	66.3
10	79.4

(7.2.5.2.6)(Continued)

(b) Draw a horizontal line from the 10% rank value on the ordinate to the best estimate line ($\overline{AB}$ on Figure 1).

(c) Draw a horizontal line from the Median Rank value of the first failure to the ordinate ($\overline{CD}$).

(d) Draw a vertical line through point B.

(e) The intersection of this vertical line and line ($\overline{CD}$) is the upper 90% confidence point for the first failure in ten (e) equipments. The following statement can now be made: There is a 90% probability that no more than 6.7% of the failures of this type equipment will occur at a stress level below S.

(f) The above procedure is utilized to determine the upper 90% confidence point for each of the remaining nine failures.

(7.2.5.2.7) Connect the ten confidence points with a smooth curve to produce an upper 90% confidence band.

(7.2.5.2.8) Extend the confidence curve until it intersects the % failure axis (1.001 x reliability boundary levels).

(7.2.5.2.9) If the ordinate value of this point of intersection is greater than 5%, the testing has demonstrated that the equipment does not meet its reliability requirements. If the ordinate value of the point of intersection is less than or equal to 5%, the equipment is considered to have met its reliability requirements.

(7.2.5.3) Sample Problem.- Ten equipment A's have successfully been taken through one mission simulation at the reliability boundary conditions of 0.08" D.A. sinusoidal vibration at a constant frequency of 100 c.p.s., and a temperature of 50°C. Upon completion of this simulation, the equipments were subjected to incremental increases in stress such that each increment represented a 10% increase in the severity of each environment (Figure 2). In the case of temperature, the 10% increments were based upon the equipment operating band of 0° C to +50°C. Failures were encountered at the following increments above the reliability boundary:

1. 10%	6. 60%
2. 20%	7. 70%
3. 30%	8. 80%
4. 40%	9. 90%
5. 50%	10. 100%

(7.2.5.3) (Continued)

These percentage increases above the reliability boundary may be converted to inches D.A. and degrees F by the table below:

	D.A.	°C
100%	0.160	100
90%	0.152	95
80%	0.144	90
70%	0.136	85
60%	0.128	80
50%	0.120	75
40%	0.102	70
30%	0.104	65
20%	0.006	60
10%	0.088	55
Rel. Bound	0.080	50

e.g., 60% increase in stress above the reliability boundary is equal to a 0.128" D.A. sinusoidal vibration at 100 c.p.s. and a temperature of 80° C.

The Median Ranks for these failures are determined as in 7.1.9.4.3, and are plotted on Weibull probability paper (Figure 3). A straight line fit is made to the Median Rank points such that the array is split 50-50. The upper 90% confidence points are plotted as described in 7.1.9.4.6, and a smooth curve is drawn to connect these points. The curve is extended in the direction of the percent failed axis and intersects this axis at a percent failure value of approximately 2.75 percent. Therefore, the equipment is considered to have demonstrated compliance with the reliability requirements (no more than 5% failures below the reliability boundary at 90% confidence).

(7.1.9.4) References. -

(1) A Summary of Some New Techniques on Failure Analysis. - John H. K. Kao, Proceedings of the Sixth National Symposium on Reliability and Quality Control, pages 190-201, 1960.

(2) The Median Ranks of Sample Values in Their Population With an Application to Certain Fatigue Studies. - Leonard C. Johnson, Research Laboratories Division, General Motors Corporation, Detroit, Michigan.

(3) Pearson, E. S. and Hartley, H. O. (ed.) Biometrika Tables for Statisticians, Table 17, Volume I, Cambridge University Press, 1954.

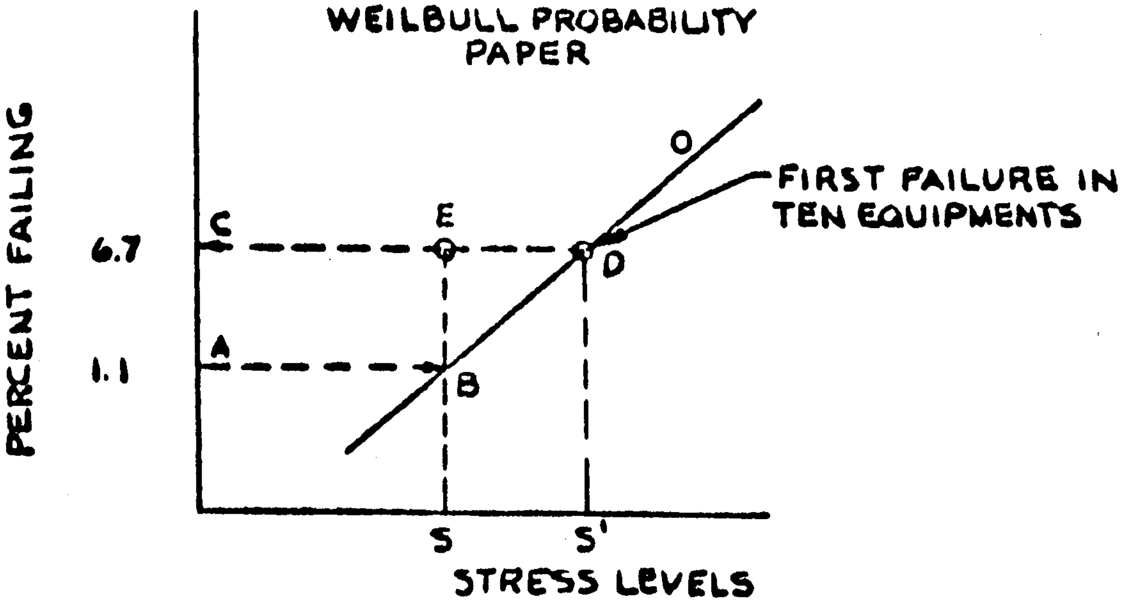


FIGURE 1

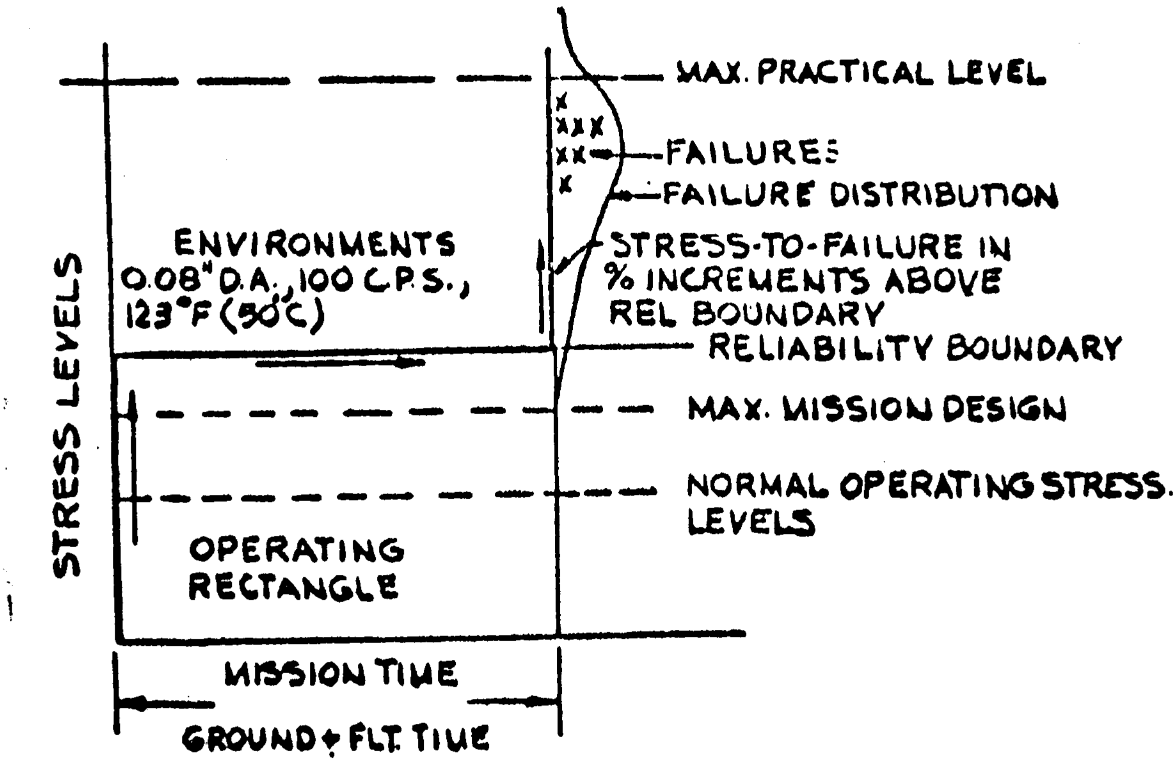
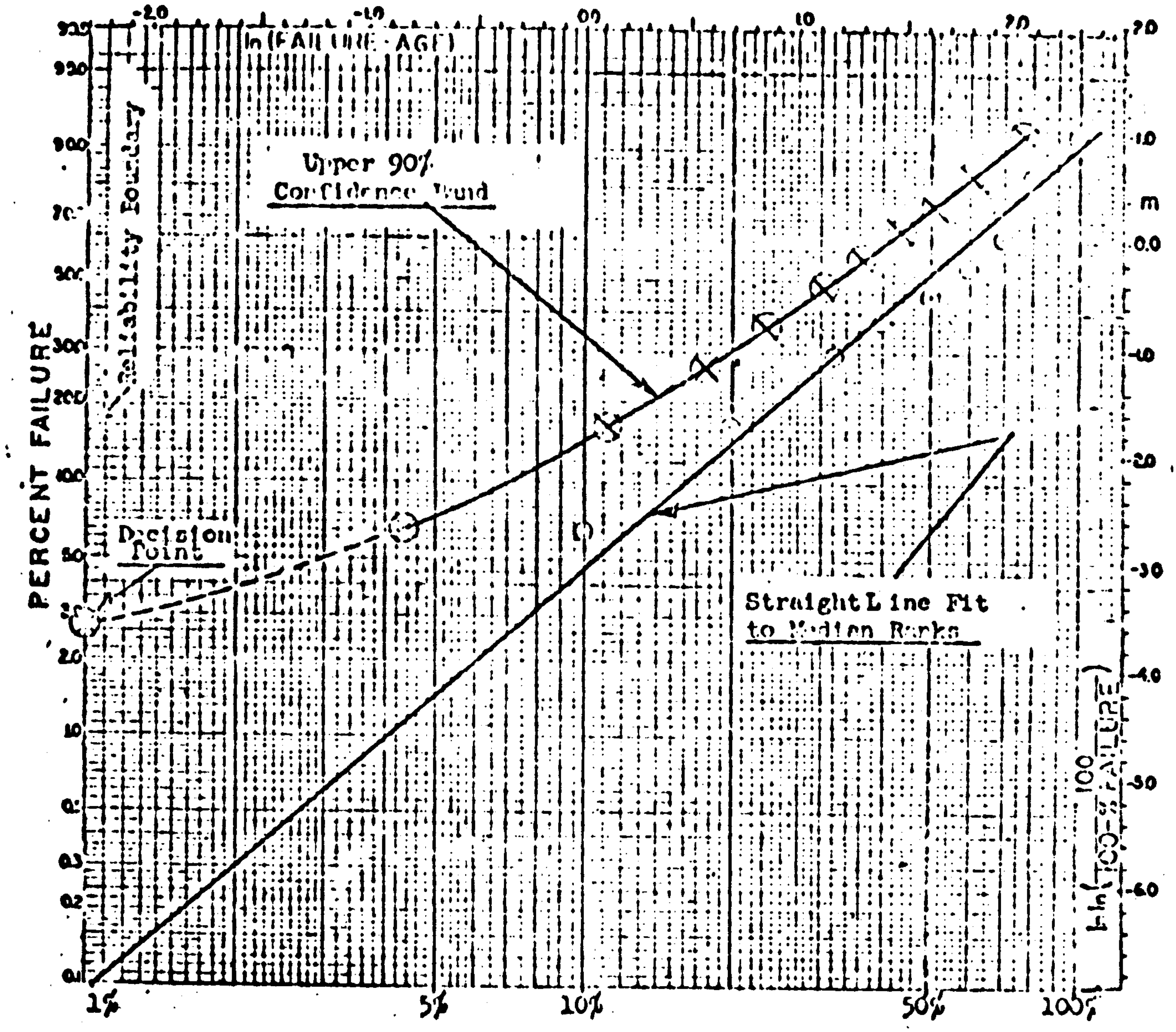


FIGURE 2

[redacted]

Weibull Probability Paper



Scale in % Above Reliability Boundary

FIGURE 3

[redacted]

SECTION G

Instructions for Proposal

6. Reliability Program - The vendor shall indicate the manpower and/or costs associated with each of the following reliability activities:

6.1 Reliability Apportionment and Estimates - As specified in paragraph 6.2.1.1 of Section C.

6.2 Configuration and Circuit Analysis - As specified in paragraph 6.2.1.2 of Section C.

6.3 Design Review Activities - As specified in paragraph 6.2.1.3 of Section C.

6.4 Failure Reporting and Analysis - As specified in paragraph 6.2.1.4 of Section C.

6.5 Documentation - As specified in paragraph 7 of Section E.

6.6 Reliability Assurance - The vendor shall specify and cost any hardware specifically added to the development program to meet the Reliability Assurance Requirements of the specification.

6.7 Support of Reliability Assurance - The vendor shall specify the manpower and/or costs associated with the Reliability Assurance requirement over and above that required for the development program for:

(a) Test facility usage
(b) Quality Control and Inspection
(c) Test labor
(d) Engineering support other than reliability

6.8 Development Test Data Contribution to Reliability - The vendor shall estimate the percentage of developmental test data that is applicable to reliability assurance other than that obtained from additional hardware specially added for the purpose.

6.9 Qualification Test Data Contribution to Reliability - The vendor shall estimate the percentage of qualification test data that is applicable to reliability assurance.

6.10 Development and Qualification Hardware - The vendor shall state the equivalent number of systems or cost of the development and of the qualification test program.

6.11 General Considerations - Any tasks of paragraph 6.1, 6.2, and 6.3 performed in other than a reliability function but applicable to the reliability activity shall be shown separately with the manpower allocated but not charged to reliability.

APPENDIX B

RELIABILITY PLAN CORRELATION WITH MIL-R-27542 AND NCP-200-2

MIL-R-27542 REQUIREMENT		RELIABILITY PLAN IMPLEMENTATION	COMMENTS
3.1	Reliability Program Considerations	Section 1	
3.2	Submission of Data	Section 5	
3.3	Design Selection Phase	Not applicable for GAEC, but to Vendors Appendix A.	See Appendix A for Vendor Requirements.
3.3.1	System Model	Section 3, Para. 3.2.2	
3.3.2	Other equipment	Section 3, Para. 3.1	
3.3.3	Program Plan	This Plan	
3.3.3.1	Reliability Organization	Section 2	
3.3.3.2		Not applicable	
3.3.3.3	Submittal of Plan	Section 5	
3.4.1	Program Implementation	Section 2, 3, 4	
3.4.2	Program Review	Section 2, Para. 2.1.2.1	
3.4.3	Periodic Reportion	Section 5	
3.5.1	Supplier and Subcontractor Reliability Programs	Appendix A Vendor Requirements	
3.5.2	Reliability Indoctrination and Training	Section 2, Para. 2.4	
3.5.3	Human Engineering	Section 3, Para. 3.3.1.6	

APPENDIX B (Continued)

MIL-R-27542 REQUIREMENT		RELIABILITY PLAN IMPLEMENTATION	COMMENTS
3.5.4	Statistical Methods	Section 3, Para. 3.3.1.8, Section 4, Appendix A	
3.5.5	Effects of Storage, Packaging, transportation, handling, and maintenance.	Section, Para. 3.3.1.1	
3.6.1	System Reliability Requirements	Section 3, Para. 3.2	
3.6.1.1	Requirement Formulation Phase	Section 3, Para. 3.2	
3.6.1.2	Design and Development Phase	Section 3, Para. 3.2	
3.6.2	Parts Reliability	Section 3, Para. 3.3.1.7	
3.6.2.1	Parts Reliability Data	Section 3, Para. 3.3.1.7.1	
3.6.3	Reliability Requirement Studies	Section 3, Para. 3.2	
3.6.4	Reliability Design Principles	Section 3	
3.6.5	Manufacturing	Manufacturing Plan LPL-850-1 and Quality Control Program Plan LPL-81-1	
3.6.6	Reliability Considerations for Engineering Changes	Section 3	
4.1	Quality Assurance	Quality Control Program Plan LPL-81-1	
4.2	Reliability Assurance	Section 5	
4.2.1.1	Design Review		

APPENDIX B (Continued)

MIL-R-27542 REQUIREMENT		RELIABILITY PLAN IMPLEMENTATION	COMMENTS
4.2.1.2	Development Testing Program	Section 4	
4.2.1.3	Maximum Preacceptance Operation	Section 3, Para. 3.3.1.7.1	
4.2.1.4.1	Demonstration Plan	Not applicable	Demonstration of achieved reliability not required. Reliability Assurance requirements have been established as a screening method - See Section 4 of this plan for description.
4.2.1.4.2	Reliability Contract Compliance Considerations	Not applicable	
4.2.1.4.3	Conditions of Test	Not applicable	
4.3	Failure Reporting, Analysis and Feedback System	Section 3, Para. 3.3.3	

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APPENDIX B (Continued)

NCP 200-2 REQUIREMENTS		RELIABILITY PLAN IMPLEMENTATION OR OTHER	COMMENTS
4.2.1	General - Design Review	Section 3, Para. 3.3.1	
4.2.2	Qualified and Preferred Parts	Section 3, Para. 3.3.1.7.1	
4.3	Qualification Test	Section 4	
4.4	Identification	Section 3, Para. 3.3.1.7.1, Section 3, Para. 3.3.2.1	
5.8	Failure and Deficiency Feedback	Section 3, Para.	

See Quality Control Program Plan for all other Paragraphs (LPL-81-1)